



WASP - A FLEXIBLE FORTRAN IV COMPUTER CODE FOR CALCULATING WATER AND STEAM PROPERTIES

by Robert C. Hendricks, Ildiko C. Peller, and Anne K. Baron Lewis Research Center Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION . WASHINGTON, D. C. . NOVEMBER 1973

WASP - A FLEXIBLE FORTRAN IV COMPUTER CODE FOR CALCULATING WATER AND STEAM PROPERTIES

by Robert C. Hendricks, Ildiko C. Peller, and Anne K. Baron
Lewis Research Center

SUMMARY

A FORTRAN IV subprogram, WASP, was developed to calculate the thermodynamic and transport properties of water and steam. The temperature range is from the triple point to 1750 K, and the pressure range is from 0.1 to 100 MN/m² (1 to 1000 bars) for the thermodynamic properties and to 50 MN/m² (500 bars) for thermal conductivity and to 80 MN/m² (800 bars) for viscosity. WASP accepts any two of pressure, temperature, and density as input conditions. In addition, pressure and either entropy or enthalpy are also allowable input variables. This flexibility is especially useful in cycle analysis. The properties available in any combination as output include temperature, density, pressure, entropy, enthalpy, specific heats (C_p and C_v), sonic velocity, $(\partial P/\partial \rho)_T$, $(\partial P/\partial T)_O$, viscosity, thermal conductivity, surface tension, and the Laplace constant.

The subroutine structure is modular so that the user can choose only those subroutines necessary to his calculations. Metastable calculations can also be made by using WASP.

INTRODUCTION

Water is inert, inexpensive, and available. It is used for cooling equipment, for heating or cooling other fluids, as a modeling fluid, and in many cases as the primary test fluid in heat-transfer and fluid dynamics research.

Printed tables of water and steam properties have been available to the engineer for many years, the latest accepted editions being references 1 and 2. Numerous computer codes to interpolate these tables using a variety of curve-fit and interpolation techniques are available. Many are cumbersome or lack the ability to calculate a consistent set of properties for a given point in the fluid surface. Some are designed for specific uses and do not include all the properties. A comprehensive, flexible, and internally consistent computer code for water properties was needed at the Lewis Research Center.

CONTENTS

Pa	ıg e
SUMMARY	1
INTRODUCTION	1
THERMODYNAMIC CALCULATIONS	2
TRANSPORT PROPERTY CALCULATIONS	4
Viscosity and Thermal Conductivity	
Near-Critical Thermal Conductivity	6
THERMODYNAMIC AND TRANSPORT PROPERTY PLOTS	6
Other Thermodynamic Functions	
Comparison Plots	
USER'S GUIDE TO WASP	
How WASD Handles Input /Output	9
How WASP Handles Input/Output	
Troubleshooting for User Errors	
	12
Problems Previously Encountered When Converting to Non-IBM Machines	
or Different FORTRAN IV - FORTRAN V Compilers	13
APPENDIXES	
A - SYMBOLS	14
B - PROPERTY EQUATIONS OF WASP	17
C - DESCRIPTION OF IMPORTANT SUBROUTINES IN WASP	22
D - MODULAR DESIGN OF WASP	20
E - PROGRAM LISTING AND FLOW CHART	oo oo
F - TEST PROGRAM WITH OUTPUT	71 71
G - METASTABLE SUBROUTINE (PMETAS)	00
H - THERMODYNAMIC RELATIONS AND DERIVATIVES	٥٥ ٩٨
DEBEDRINGS	50

I		

1. Report No. NASA TN D-7391	2. Government Accessi	on No.	3. Recipient's Catalog	No.
4. Title and Subtitle			5. Report Date	
WASP - A FLEXIBLE FORTRA	N IV COMPUTER	R CODE FOR	November	1973
CALCULATING WATER AND S		1	6. Performing Organiz	ation Code
7. Author(s)			8. Performing Organiza	ation Report No.
Robert C. Hendricks, Ildiko C.	e K. Baron	E-7339		
			10. Work Unit No.	
Performing Organization Name and Address			502-04	
Lewis Research Center		1	11. Contract or Grant	No.
National Aeronautics and Space	Administration			
Cleveland, Ohio 44135		1	Type of Report an	d Period Covered
12. Sponsoring Agency Name and Address			Technical No	te
National Aeronautics and Space Washington, D.C. 20546	Administration		14. Sponsoring Agency	Code
15. Supplementary Notes				
16. Abstract				
A FORTRAN IV subprogram, V	VASP, was develo	oped to calculate the	e thermodynami	c and trans-
port properties of water and st	eam. The tempe	rature range is from	n the triple poir	it to 1750 K,
and the pressure range is from	0.1 to 100 MN/n	${ m n}^2$ (1 to 1000 bars):	for the thermod	ynamic prop-
erties and to 50 MN/m^2 (500 ba	ers) for thermal o	conductivity and to {	$80 \; \mathrm{MN/m}^2 \; (800)$	bars) for
viscosity. WASP accepts any t				
In addition, pressure and eithe				
flexibility is especially useful				
as output include temperature,				
as output include temperature, C_{v} , sonic velocity, $(\partial P/\partial \rho)_{T}$,				
and the Laplace constant. The				
only those subroutines necessa	ry to mis calculat	ions. wetastable c	aiculations can	areo ne maue
by using WASP.				
17. Key Words (Suggested by Author(s))		18. Distribution Statement		
Thermodynamics		Unclassified - u	ınlimited	
Computers				
Properties of water and steam				
10 Security Clearly (of this years)	20. Security Classif. (o	f this name)	21. No. of Pages	22. Price*
19. Security Classif. (of this report) Unclassified	1	lassified	118	Domestic, \$4.25

In determining the coefficients of equation (1), the temperature data were all expressed on the thermodynamic Celsius temperature scale. Since experimental observations for water, however, are usually reported in terms of the International Practical Scale (the I. P. Scale), a lengthy discussion and a graph of the relation between the I. P. Scale and the thermodynamic temperature scale are presented in reference 3. ²

The critical constants of reference 3 differ from those presented in references 1 and 2 as follows:

	Refer- ence 3	References 1 and 2
Critical pressure, P _c , MN/m ²	22.089	22. 120
Critical tempera-	374.02	374. 15
ture, T_c , ^{o}C Critical density, $ ho_c$, g/cm^3	0.317	0. 31546

The temperatures in this table are on the I. P. Scale. The critical temperature T_c of reference 3 on the thermodynamic scale is 374.136° C.

The WASP subprogram was developed to be used in fluid-flow and heat-transfer calculations. There are independent calls for obtaining any one of the three state variables (pressure, density, and temperature) as a function of the other two (see table I, OPERATIONS SHEET FOR SUBROUTINE WASP). In addition, temperature and all the other properties can be obtained as a function of pressure and enthalpy (or pressure and entropy). This option is of considerable value in forced-convection studies and cycle analysis.

While enthalpy, entropy, and specific heats (C_p and C_v) are available in reference 3, the sonic velocity, viscosity, thermal conductivity, and surface tension were not computed in reference 3. The sonic velocity, equation (B30), is defined in terms of equation (1). The transport properties are discussed in the following section.

TRANSPORT PROPERTY CALCULATIONS

The thermal conductivity, viscosity, and surface tension are available in references

²Differences between the current conversion from Celsius to I.P. Scale and that of ref. 3 are small except at elevated temperatures. These deviations did not warrant our reexamination of equation (1).

	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v), sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar by using WASP. Key Words (Suggested by Author(s)) Thermodynamics Computers Properties of water and steam Security Classif. (of this report)	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input valle input varia vailable in any cpy, specific heauctivity, surface that the user calculations can	bars) for conditions. bles. This combination ts (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v , sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar by using WASP.	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow halpy are also allow. The properties are, entropy, enthal esity, thermal conducture is modular so tions. Metastable of the conducture is modular so tions.	80 MN/m ² (800 density as input valle input varia vailable in any cpy, specific heauctivity, surface that the user calculations can	bars) for conditions. bles. This combination ts (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, $C_{\rm V}$), sonic velocity, $(\partial {\rm P}/\partial \rho)_{\rm T}$, and the Laplace constant. The only those subroutines necessar by using WASP.	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow halpy are also allow. The properties are, entropy, enthal esity, thermal conducture is modular so tions. Metastable of the conducture is modular so tions.	80 MN/m ² (800 density as input valle input varia vailable in any cpy, specific heauctivity, surface that the user calculations can	bars) for conditions. bles. This combination ts (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_{v} , sonic velocity, $(\partial P/\partial \rho)_{T}$, and the Laplace constant. The only those subroutines necessar by using WASP.	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific heauctivity, surface that the user ca	bars) for conditions. bles. This combination ts (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v), sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific heauctivity, surface that the user ca	bars) for conditions. bles. This combination its (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v), sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific heauctivity, surface that the user ca	bars) for conditions. bles. This combination its (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v), sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific heauctivity, surface that the user ca	bars) for conditions. bles. This combination its (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature, C_v), sonic velocity, $(\partial P/\partial \rho)_T$, and the Laplace constant. The only those subroutines necessar	wo of pressure, rentropy or entle n cycle analysis density, pressu $(\partial P/\partial T)_{\rho}$, viscosubroutine structure.	temperature, and chalpy are also allow . The properties a re, entropy, enthal esity, thermal conducture is modular so	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific heauctivity, surface that the user ca	bars) for conditions. bles. This combination its (C _p and e tension, an choose
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i as output include temperature,	wo of pressure, r entropy or entl n cycle analysis density, pressu	temperature, and of halpy are also allow . The properties a re, entropy, enthal	80 MN/m ² (800 density as input vable input varia vailable in any cpy, specific hea	bars) for conditions. bles. This combination ts (C _n and
	viscosity. WASP accepts any t In addition, pressure and either flexibility is especially useful i	wo of pressure, r entropy or entl n cycle analysis	temperature, and chalpy are also allow. The properties a	80 MN/m ² (800 density as input vable input varia vailable in any c	bars) for conditions. bles. This combination
	viscosity. WASP accepts any t In addition, pressure and either	wo of pressure, r entropy or entl	temperature, and chalpy are also allow	80 MN/m ² (800 density as input vable input varia	bars) for conditions.
	viscosity. WASP accepts any t	wo of pressure,	conductivity and to temperature, and	$80 \text{ MN/m}^2 (800)$	bars) for
	erties and to 50 MN/m (500 pa	irsi tor thermal		2 (2.2	aynamic prop-
	and the pressure range is from	0.1 to 100 MN/	m^2 (1 to 1000 bars)	for the thermod	transmis mass
	port properties of water and ste	eam. The temp	erature range is fro	om the triple poi	nt to 1750 K.
10.	A FORTRAN IV subprogram, W	VASP. was deve	loned to calculate th	ne thermodynami	ic and trans-
16	Abstract			***	
15.	Supplementary Notes				
15	Washington, D. C. 20546 Supplementary Notes				
	National Aeronautics and Space	Administration		14. Sponsoring Agenc	y Code
12.	Sponsoring Agency Name and Address			Technical N	
	Cleveland, Ohio 44135			13. Type of Report a	and Period Covered
	National Aeronautics and Space	Administration	;	11. Contract or Gran	t No.
	Lewis Research Center			502-04	
9.	Performing Organization Name and Address		10. Work Unit No.		
7.	Author(s) Robert C. Hendricks, Ildiko C.	nne K. Baron	8. Performing Organi E-7339	ization Report No.	
		TEAM PROPER	TILES	g or go	
ĺ	WASP - A FLEXIBLE FORTRACE CALCULATING WATER AND S			November 6. Performing Organ	
	Title and Subtitle			5. Report Date	1000
4.	NASA TN D-7391	2. Government Acce	ssion No.	3. Recipient's Catalo	og No.
L	Report No.	2. Government Acce			

WASP is a FORTRAN IV subprogram developed for engineering calculations. The thermodynamic properties are calculated by using the Helmholtz free-energy equation developed by Keyes, Keenan, Hill, and Moore (ref. 3). The transport properties are calculated by using curve fits given in references 1 and 2 in regions where these equations exist. The authors developed their own approximations based on the tabulated values of references 1 and 2 where curve fits were not available.

The main section of this report is directed to the research-oriented user of WASP. It includes a brief discussion of the equations used in calculating thermodynamic and transport properties. Comparisons to the International Skeleton Tables and the validity of transport calculations are also discussed. A detailed presentation of user instructions is included together with a tabular summary for later reference. Detailed information about the computer program and the equations used are included as appendixes. The symbols are defined in appendix A; the property equations of WASP are given in appendix B; the important subroutines of WASP are described in appendix C; the modular design of WASP is presented in appendix D; the program listing and flow chart are presented in appendix E, the test program output in appendix F, the metastable subroutine PMETAS in appendix G, and the thermodynamic relations and derivatives in appendix H.

THERMODYNAMIC CALCULATIONS

Keyes, Keenan, Hill, and Moore (ref. 3) fit the available experimental water and steam data from the triple point to a pressure of $100~\mathrm{MN/m}^2$ and to a temperature of about 1750 K, using the fundamental equation

$$\psi = \psi(\mathbf{T}, \rho)$$

$$= \psi_0(\mathbf{T}) + \mathbf{R}\mathbf{T} \left[\ln \rho + \rho \mathbf{Q}(\rho, \tau) \right]$$
(1)

where ψ is the specific Helmholtz free energy and $\tau = 1000/T$. The specific forms of $\psi_0(T)$, $Q(\rho, \tau)$, and the derivatives of $Q(\rho, \tau)$ are presented in appendix B.

Most investigators (e.g., refs. 4 to 7), in order to represent their measured values as closely as possible, have selected a modified virial equation of state

$$P = P(T, \rho)$$

$$= \sum_{i=1}^{6} A_{i}(T)\rho^{i} + \sum_{j=1}^{2} B_{j}(T)\rho^{2j+1}e^{-c\rho^{2}}$$
(2)

where P is the pressure and the coefficients $A_i(T)$ and $B_j(T)$ are usually polynomials in T and T^{-1} .

While the derivation of pressure from equation (1) is quite simple,

$$\mathbf{P} = \rho^2 \left(\frac{\partial \psi}{\partial \rho} \right)_{\mathbf{T}}$$

$$= \rho RT \left(1 + \rho Q + \rho^2 \frac{\partial Q}{\partial \rho} \right) \tag{3}$$

the ensuing expanded descriptions for both equations (2) and (3) are quite involved, see appendix B and reference 8.

One should note the influence of the modified forms of the Benedict-Webb-Rubin (BWR) equation of state (see refs. 4 to 6) and the more recent work of Bender (ref. 7) on equation (1). (Compare the form of Q in eq. (B4) of appendix B with eq. (2).) The authors of references 5 and 6 added new exponential terms to the BWR equation of reference 4 to account for high-density effects. The technique has been successfully applied to several cryogens. More recently, Bender (ref. 7), in addition to these modifications, imposed another constraint, namely that the Maxwell Phase Rule must be satisfied; the constraint requires that the Gibbs free energy for the saturation liquid and vapor be equal. This latter constraint, although not stated explicitly, is implicitly satisfied by equation (1) (taken from ref. 3) because the Gibbs free energy of the saturated liquid and vapor are "virtually identical."

Both equations (1) and (2) have been fit by using a weighted least-squares technique which minimizes the residuals in pressure subject to various constraints such as

$$\left(\frac{\partial \mathbf{P}}{\partial \rho}\right)_{\mathbf{T}} = 0$$
 $\left(\frac{\partial^2 \mathbf{P}}{\partial \rho^2}\right)_{\mathbf{T}} = 0$ $\rho = \rho_{\mathbf{c}}$ $\mathbf{T} = \mathbf{T}_{\mathbf{c}}$

at the thermodynamic critical point. Reference 3 cites 14 such constraints; usually, the number is about one-half as many. However, the advantage of the reference 3 approach is that ψ as a function of ρ and T is a <u>fundamental</u> equation and all thermodynamic properties are obtained directly from ψ and its derivatives. In equation (2), P as a function of ρ and T is a <u>state</u> equation. In determining properties such as enthalpy, entropy, and specific heats, the state equation must be differentiated and integrated and the associated constants of integration must be determined from other data. ¹

¹The mathematical form of the derived and integrated equations must be such that they do not possess singularities except at the critical point.

In determining the coefficients of equation (1), the temperature data were all expressed on the thermodynamic Celsius temperature scale. Since experimental observations for water, however, are usually reported in terms of the International Practical Scale (the I. P. Scale), a lengthy discussion and a graph of the relation between the I. P. Scale and the thermodynamic temperature scale are presented in reference 3. ²

The critical constants of reference 3 differ from those presented in references 1 and 2 as follows:

	Refer- ence 3	References 1 and 2
Critical pressure, P _c , MN/m ²	22.089	22. 120
Critical tempera-	374.02	374. 15
ture, T_c , ^{o}C Critical density, $ ho_c$, g/cm^3	0. 317	0. 31546

The temperatures in this table are on the I. P. Scale. The critical temperature $\, T_c \,$ of reference 3 on the thermodynamic scale is 374.136 $^{\rm O}$ C.

The WASP subprogram was developed to be used in fluid-flow and heat-transfer calculations. There are independent calls for obtaining any one of the three state variables (pressure, density, and temperature) as a function of the other two (see table I, OPERATIONS SHEET FOR SUBROUTINE WASP). In addition, temperature and all the other properties can be obtained as a function of pressure and enthalpy (or pressure and entropy). This option is of considerable value in forced-convection studies and cycle analysis.

While enthalpy, entropy, and specific heats $(C_p \text{ and } C_v)$ are available in reference 3, the sonic velocity, viscosity, thermal conductivity, and surface tension were not computed in reference 3. The sonic velocity, equation (B30), is defined in terms of equation (1). The transport properties are discussed in the following section.

TRANSPORT PROPERTY CALCULATIONS

The thermal conductivity, viscosity, and surface tension are available in references

²Differences between the current conversion from Celsius to I.P. Scale and that of ref. 3 are small except at elevated temperatures. These deviations did not warrant our reexamination of equation (1).

1 and 2, with the exception of a small region near the thermodynamic critical point for thermal conductivity and a large region (573 to 647.3 K) for viscosity. For these regions, the tabulated values of references 1 and 2 represent the output of some interpolation scheme. However, no technique for predicting transport properties in these regions is given in these references.

Viscosity and Thermal Conductivity

Reference 8 uses the simple empirical technique of reference 9 to express the viscosity η and thermal conductivity λ of several fluids. An excess function of density ρ is added to the dilute gas function of temperature T such that

$$\eta = \eta_1 + \Delta \eta \tag{4}$$

$$\Delta \eta = \eta - \eta_1 = \mathbf{F}(\rho) \tag{5}$$

$$\eta_1 = F(T) \quad \text{at } P = 0.1 \text{ MN/m}^2$$
(6)

and

$$\lambda = \lambda_1 + \Delta \lambda \tag{7}$$

$$\Delta \lambda = \lambda - \lambda_1 = \mathbf{F}(\rho) \tag{8}$$

$$\lambda_1 = F(T)$$
 at $P = 0.1 \text{ MN/m}^2$ (9)

We used this technique to obtain viscosity and thermal conductivity in the regions where no equation existed in references 1 and 2.

The $\Delta \eta$'s shown in figure 1 were obtained from the tabulated and computed data in references 1 and 2. These data were then extrapolated through the region where no fit is available (region 4) to predict the viscosity in that region.

Figure 1 gives a good representation for viscosity over a considerably larger range than 573 to 647.3 K, with deviations from the tabulated data up to 7 percent in some regions and perhaps 10 percent in the critical region. References 1 and 2 list uncertainties at ±4 percent in those regions where the values were not interpolated, and no uncertainties are given for the interpolated region. The analytical representations of viscosity are given in appendix B.

The $\Delta\lambda$'s used to predict thermal conductivity were also obtained from the tabulated and computed data of references 1 and 2. In this case the scatter is more acute

over a wide range of density because these data are pressure sensitive and are not entirely represented by excess thermal conductivity as a function of density, see figure 2. While the curve of figure 2 represents a wider P,T range than the region where no curve fit is available (region V) in figure 2, the $\Delta\lambda$ curve fit is used only in region V.

Generally, deviations to 8 percent in λ -calculations can be found with respect to the tabulated data. References 1 and 2 give the deviations as ± 4 percent in regions where curve fits exist, and no uncertainties are listed for the interpolated region. The analytic forms for thermal conductivity are given in appendix B. In region IV (fig. 2) the implicit equation for thermal conductivity from reference 2 is used. In region III an explicit expression for thermal conductivity from reference 2 is used. These forms were adopted over those of reference 1 because of their analytic nature.

The 0.1-MN/m² thermal conductivity and viscosity output from 700 to 1700 K was checked against the results of Svehla (ref. 10). Svehla's viscosity is 5 to 10 percent higher and his thermal conductivity is 10 to 15 percent higher than those predicted herein. Since the publishing of reference 10, Svehla has found that inclusion of a rotational relaxation effect would lower his calculated viscosity perhaps 5 percent, and lower his calculated thermal conductivity perhaps 10 to 15 percent.

Near-Critical Thermal Conductivity

The anomalous behavior of thermal conductivity in the near-critical region was measured by Le Neindre (ref. 11). Sengers (ref. 12) advanced a technique to predict the behavior of near-critical thermal conductivity data for carbon dioxide. In reference 13, Sengers' technique was modified, extended to several fluids, and compared with other methods. The technique used herein is the same as Sengers' technique as presented in reference 13, except that the proportionality constant, 3.05×10^{-5} as given by Sengers in reference 12, has been increased to 11.6×10^{-5} .

THERMODYNAMIC AND TRANSPORT PROPERTY PLOTS

Sample plots of the properties calculated by WASP are found in figures 3 to 14. ³ The triple temperature scales in these figures are to facilitate checking. Figure 3 represents density as a function of temperature for selected isobars, including the critical isobar. No irregularities were found. Figure 4(a) represents the pressure as a function of temperature for selected isochores. These isochores exhibit distinct curvature not only near the saturation boundaries but in the extended regions as well. The slopes

 $^{^3}$ Isobars which cross the saturation boundaries are parallel to isotherms. The plotting routine simply connects increments in temperature.

of the isochores as a function of temperature are shown in figure 4(b), which reveals the nonlinear character of most of the isochores of figure 4(a). Figure 5 represents the pressure-volume (P-V) plane for selected isotherms. Local P-V regions could be mapped by using WASP for preliminary cycle analysis. Figure 6 represents enthalpy as a function of temperature for selected isobars, including the critical isobar. Figure 7 represents the temperature-entropy (T-S) diagram for selected isobars. Again, local T-S regions could be mapped by using WASP for preliminary cycle analysis.

Figure 8 represents specific heat at constant pressure and figure 9(a) represents specific heat at constant volume for selected isobars, including the critical isobar. Note the peaking effects in C_v along the critical isobar; this indicates a discontinuity in C_v , as well as in C_p , along the critical isobar. This behavior agrees with the most recent thinking on C_v in the critical region; namely, that C_v possesses a weak logarithmic infinity (i. e., $C_v \cong |T-T_c|^{-0.06}$, as discussed in ref. 14). In figure 9(b), the isentropic expansion coefficient ($\gamma = C_p/C_v$) is given as a function of temperature for selected isobars, including the critical isobar. Note that while C_p and C_v tend toward a discontinuity, so also does the ratio. The reason is that C_p possesses a very strong "infinity" at the critical point $\left(C_p \cong \left|T-T_c\right|^{-\beta}1$, where $1.2 \le \beta_1 \le 1.35\right)$ and C_v a rather weak "infinity." Consequently, in the critical region, γ diverges approximately as $\left|T-T_c\right|^{-\beta}2$, where $1.1 \le \beta_2 \le 1.3$. Figure 10 gives sonic velocity as a function of temperature for selected isobars.

Figure 10 gives sonic velocity as a function of temperature for selected isobars Sonic velocity tends toward zero, or at least a minimum, in the critical region C_c , which also concurs with recent thinking because

$$C_{\mathbf{c}} \propto \frac{1}{\rho} \sqrt{\frac{T}{C_{\mathbf{v}}}} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\rho}$$

Since C_v diverges in a weak manner and $(\partial P/\partial T)_\rho$ is nonzero and finite, C_c will approach zero in a weak manner.

Figure 11 represents a plot of viscosity as a function of temperature along selected isobars, including the critical isobar. The discontinuities of this surface at 573 and 647 K are caused by the empirical nature of the curve fit (fig. 1), as discussed previously. This discontinuity is on the average less than 4 percent, which is the same order of accuracy as presented in references 1 and 2.

Figure 12(a) represents thermal conductivity as a function of temperature along selected isobars. In this report, an attempt has been made to include the anomalous behavior of thermal conductivity in the near-critical regions based on references 12, 13, 15, and 16. The behavior of the near-critical thermal conductivity is shown in figure 12(b). In order for the user to obtain these values, he must add EXCESSK, which represents the anomalous part of the thermal conductivity, to the normally computed

value of thermal conductivity. See USER'S GUIDE TO WASP, the statement COMMON/PROPTY/... Generally, the plots of η and λ exhibit some irregularities where the various predicting techniques overlap; however, for most applications the values returned are within acceptable tolerance.

Figure 13 is a plot of surface tension σ and Laplace constant as a function of temperature. Metastable conditions near both the liquid and vapor are often required in a system analysis and can be calculated by equation (1). A special subroutine is included in appendix G which when used with WASP will give metastable properties; sample plots are shown as figure 14.

Other Thermodynamic Functions

WASP provides sufficient PVT and derived property data for most users; however, if other functions are required, the user may calculate these by using the partial derivatives $(\partial P/\partial \rho)_T$ and $(\partial P/\partial T)_\rho$, along with the other results from WASP. Appendix H is provided to give the user a handy reference to the so-called Bridgeman Tables which list most of the interrelations between thermodynamic variables. (See pp. 36 and 64.)

Comparison Plots

Of utmost importance is how well equation (1), as used in WASP, agrees with the International Skeleton Tables for steam and water (refs. 1 and 2). Figures 15 to 17 were obtained by running all the data points listed in table 1. 2 of reference 1 (see also table 4b of ref. 2) on each of the three input options (T,P), (ρ,T) , and (ρ,P) in WASP. Each of the figures is discussed, but the careful reader should note that discrepancies exist in the specific volumes presented in these two references. The authors noted four obvious errors in reference 2 by comparing references 1 (table 1. 2) and 2 (table 4b). Reference 1 was assumed to be correct. Other discrepancies occur in reference 2, for instance in the specific heat C_p . No attempt was made to track all these errors, and the reader should use reference 2 cautiously.

Figure 15 represents the percent relative error in density, $[(\rho_{\rm table} - \rho_{\rm calc})/\rho_{\rm table}] \times 100$, as a function of density. With the exception of three points, all the values are within +0.25 percent and -0.50 percent, and generally have an error of less than 1 part in 3000. The solution for density is iterative, and perhaps the error could be reduced somewhat by a tightening of the convergence criteria. This is not recommended for two reasons: (1) It will require a great increase in computer time, and (2) errors in these printed tables have been noted. The tolerance should be quite satisfactory to all but the most critical user.

Figure 16 represents the percent relative error in pressure, $[P_{table} - P_{calc}]/P_{table} \times 100$, as a function of pressure. In all cases the calculated pressures are within +3.0 percent and -2.0 percent of the tabulated value; most points lie within +0.25 percent of the tabulated value. The prediction of pressure at high density (low temperatures) using a fundamental equation or a state equation is quite difficult. These pressure errors are all within accepted tolerances.

Figure 17 represents the percent relative error in temperature, $[(T_{table} - T_{calc})/T_{table}] \times 100$, as a function of temperature. With the exception of about a dozen points, the predicted temperatures are within +0.25 percent and -0.4 percent and generally lie within ±0.1 percent.

Usually, temperature and density are predictable because of the manner in which the data were acquired; however, pressure is always difficult to calculate. With these basic guidelines in mind and figures 15 to 17, it can be said that the equation gives a faithful representation of the International Skeleton Tables (refs. 1 and 2).

USER'S GUIDE TO WASP

The user with limited programming experience should have no difficulty in following the operating instructions for WASP. After gaining a little experience with WASP, the only references needed are table I (the operations sheet) and table II (the units specification).

How WASP Handles Input/Output

WASP is a group of subroutines designed to be used as a subprogram with the user's program. Standard communication between the user's program and WASP is achieved by the following two FORTRAN statements, which contain the symbols representing the input/output parameters and options:

COMMON/PROPTY/KU, DL, DV, HL, HV, etc. CALL WASP (KS, KP, T, P, D, H, KR)

See table I and appendix A.

Three requirements must be fulfilled for a successful call to WASP:

(1) The cards for COMMON/PROPTY/KU, DL, DV, etc., must be included in the user's main program or the subroutine that calls WASP. The WASP subprogram deck must be correctly loaded with the user's program as shown in table III. The variables MU, MUL, MUV, K, KL, and KV must be declared REAL. (K cannot be used as an

index for a subscripted variable.) However, the user can change the names of these variables in COMMON/PROPTY/KU, DL, DV, etc.,

(2) The units system for input/output must be correctly specified. KU is an input control specified in the COMMON/PROPTY/KU, DL, DV, etc., which must be set such that $1 \le KU \le 5$. KU identifies the units system for input/output, and KU is never altered by WASP. Therefore, unless the user switches from one system to another, he need set his value for KU only once, before any calls to subroutine WASP.

There are three specified units options described in table II. The option KU=1 is the internal program units system. The other two options are commonly used in engineering calculations. If the user does not wish to use one of these options, he can specify any desired units system for KU=4 and KU=5, provided the conversion factors for this system are stored by the user as directed in table II.

(3) The controls KR, KS, and KP, which tell WASP what variables are to be used as input and what properties are requested for output, must be correctly initialized in the call statement for subroutine WASP. The corresponding input variables in the call statement and COMMON/PROPTY/... must also be correctly initialized.

KS and KR are controls that determine which of the variables T, P, D, H, or S or combinations thereof are needed as thermodynamic input. KP is an input control which specifies which properties are sought as output.

KR is also an output variable since it gives the correct region number for the variables in a specific call to WASP, as shown in the sketch in table I. Depending on the input for KS and KP, the other possible output variables are T, P, D, H, and all of COMMON/PROPTY/ except the control KU.

As mentioned above, \underline{KR} is both input and output and $\underline{must\ be\ reset}$ before each call to WASP. The input options are

- (a) KR=0 when user wishes WASP to determine a value for KR
- (b) KR=1 when user wishes saturation conditions⁴

The output for KR will be

- (a) KR=1 for saturation
- (b) KR=2 for liquid
- (c) KR=3 for vapor

KS specifies which variables are to be used as input for a call to subroutine WASP. (In the remaining discussion on WASP input/output, the input variables are assumed to be in user's units specified by KU. Output is always returned in the KU system of units.)

⁴Saturation or coexistence conditions exist on the PVT surface when pressure is a function of only temperature and the liquid and vapor states both exist at that pressure. Thus when KR=1, two outputs for each property are available in COMMON/PROPTY/ and only one independent variable is required for some input options, as shown in the KS-KR input/output chart.

The following table shows the input and output for all KS, KR combinations:

Thermodynamic		State rela	ation speci	fication, KS	
region specifica- tion, KR	1	2	3	4	5
		Input			
0 1	T and P T or P ^a	T and D T	P and D	P and H P	P and S
	Output				
1	T or P ^a , DL and DV	Р	Т	T, DL, DV	T, DL, DV
2 3	D D	P P	T T	D and T D and T	D and T D and T

^aIf T is the desired input, set P = 0.0 prior to the call and vice versa. Then WASP will return the correct saturation value for the 0.0 input. If both T and P have an input value $\neq 0.0$, WASP uses T but will not alter P input.

<u>KP</u> is an input control that specifies which derived and transport properties are re quested by the user. It is the sum of the individual KP options and is described in table I. This binary sum allows WASP to uniquely identify any combination of requests. The following table shows the output locations for the specific KR and KP combinations:

Value added to KP input	_	Output for KR=1		Name of calculated property
to KF Input	KR=2 0r 3	Liquid	Vapor	
0				None requested
1	Н	HL	HV	Enthalpy
2	S	SL	sv	Entropy
[]	CP	CPL	CPV	Specific heat at constant pressure
4 }	CV	CVL	CVV	Specific heat at constant volume
	GAMMA	GAMMAL	GAMMAV	Specific-heat ratio
	C	CL	CVP	Sonic velocity
8	MU	MUL	MUV	Viscosity
16	K	KL	KV	Thermal conductivity
1	SIGMA	SIGMA		Surface tension of the liquid as a
32				function of temperature
	ALC	ALC		Laplace constant as a function of
		1		temperature

Troubleshooting for User Errors

After experience with WASP, we have found that several common errors are easily detected and corrected.

- (1) Failure to set $1 \le KU \le 5$ will cause a ''division by 0.0'' and/or no valid answers. Set KU to its proper value.
- (2) Failure to set $1 \le KS \le 5$ will most likely cause a halt to the program because of an execution error. The branching on KS in subroutine WASP is a computed "GO TO." Simply set KS to its proper value.
- (3) Failure to set KP will return enthalpy if KP is odd and no derived properties if KP is even.
- (4) If a wrong value is entered for KR, it is treated as KR=0. If a user enters KR=1 when he does not want saturation properties, he will get them anyway for $\rm T < \rm T_{\rm C}$ and otherwise will get a wrong answer.
- (5) If any T, P, D, H, or S is entered incorrectly, that value will be used and the answer will be wrong.
- (6) If the COMMON/PROPTY/ is duplicated incorrectly, there are a variety of possible errors, almost all serious.

Other small problems may be encountered if WASP is modified for different compilers or computers. The FORTRAN IV coding in WASP is machine independent except for a few Hollerith format statements which can be easily changed. The reader who needs more detailed information should read the appendixes.

Additional Information

The approximate core storage for the complete WASP program is $(14650)_8 = (6568)_{10}$ locations.

The time estimates were obtained by running an average of 100 calls over the entire PVT range for each option indicated. The shortest call was for pressure, KS=2, at an average of 4 milliseconds per call for $T > T_c$ and 17 milliseconds for $T \le T_c$. The call for density, KS = 1, varied from 17 to 40 milliseconds for all regions, with the greatest time being consumed in the near-critical region. The call for temperature, KS=3, varied from 11 to 70 milliseconds per call, with the least time used when $P > P_c$ and the most time used in the near-critical region. The call for density and all the derived properties, KS=1 and KP=63, varied from 38 to 120 milliseconds per call depending on the density call and the regions for the transport properties.

The P, H and P, S calls, KS=4 and KS=5, each required from 300 to 800 milliseconds per call, with the greatest time in the near-critical region. These results are summarized as follows:

	Sta	ite relatio	n specificati	on, KS	•
1	2	3	4	5	1
Thermo	odynamic	and transp	ort properti	es specifica	tion, KP
0	0	0	0	0	63
		Time,	msec/call		
17 to 40	4 to 17	11 to 70	300 to 800	300 to 800	38 to 120

Problems Previously Encountered When Converting to Non-IBM Machines or Different FORTRAN IV - FORTRAN V Compilers

The problems encountered in converting to different equipment are as follows:

- (1) IBM 360 users should run in double precision by inserting implicit REAL*8 (A-H, O-Z) and REAL*8 MU, MUL, MUV, K, KL, KV in subroutine WASP and implicit REAL*8 (A-H, O-Z) in all other subroutines. Change COMMON/PROPTY/KU, KZ, DL, DV, etc., for proper alinement.
- (2) Data statements are found in subroutines BLOCK DATA, THERM, VISC, and SURF. Many compilers differ in formating data statements.
- (3) The multiple-entry routine (CHECK, TCHECK, PCHECK, DCHECK) has an entry point, DCHECK, whose input vector (KU, D) does not correspond in kind and number with the other entry points (KU, KR, T) or (KU, KR, P). To our knowledge this has caused a problem on only one compiler, a FORTRAN IV for a CDC 3800. It was easily remedied by an equivalence statement.

The authors adapted the code to fit the following compilers and machines: UNIVAC 1108, CDC 3600, CDC 6600, IBM 360/67TSS, and IBM 7094-7044 DCS.

Lewis Research Center,

National Aeronautics and Space Administration, Cleveland, Ohio, April 26, 1973, 502-04.

APPENDIX A

SYMBOLS

Mathemat- ical symbol	FORTRAN symbol ⁵	Definition
$\mathbf{A_{ij}}$	A (I, J)	coefficients of terms in Q-function (see table IV)
·	ALC	Laplace constant
c	С	sonic velocity, cm/sec
	CL	sonic velocity of saturated liquid, cm/sec
	CVP	sonic velocity of saturated gas, cm/sec
C_1	SIC1	
		coefficients of terms in ψ_0 function (see table IV)
C ₅	SIC5	
$C_{\mathbf{p}}$	CP	specific heat at constant pressure, $J/(g)(K)$
•	CPL	specific heat C_p of saturated liquid, $J/(g)(K)$
	CPV	specific heat C_p of saturated vapor, $J/(g)(K)$
$^{\mathrm{C}}\mathrm{_{v}}$	CV	specific heat at constant volume, $J/(g)(K)$
	CVL	specific heat C_v of saturated liquid, $J/(g)(K)$
	CVV	specific heat C_v of saturated vapor, $J/(g)(K)$
D ₁	CPS1	
	. }	coefficients for vapor pressure curve (see table IV)
	· CDG7	
D ₇	CPS7	$\mathbf{E} = 4.8$
Е	E	
Н	Н	enthalpy, J/g
	$^{ m HL}$	enthalpy of saturated liquid, J/g

⁵Symbols used in each individual subroutine are identified in that subroutine (see appendix C).

	HV	enthalpy of saturated vapor, J/g
	KP	thermodynamic and transport properties specification
	KR	thermodynamic region specification
	KS	state relation specification
	KU	units specification
.P	P	pressure, MN/m ²
Q	QCALC	data-fitting function
R	R	specific gas constant for water, 0.46151 $J/(g)(K)$
S	S	entropy, $J/(g)(K)$
	SL	entropy of saturated liquid, $J/(g)(K)$
	sv	entropy of saturated vapor, J/(g)(K)
Т	Т	temperature, K
u		internal energy, J/g
γ	GAMMA	ratio of specific heats, C_p/C_v
	GAMMAL	ratio of specific heats for saturated liquid
	GAMMAV	ratio of specific heats for saturated vapor
η	$\mathbf{M}\mathbf{U}$	dynamic viscosity, g/(cm)(sec)
	MUL	dynamic viscosity of saturated liquid, g/(cm)(sec)
	MUV	dynamic viscosity of saturated vapor, g/(cm)(sec)
λ	K	thermal conductivity, W/(cm)(K)
	KL	thermal conductivity of saturated liquid, W/(cm)(K)
	KV	thermal conductivity of saturated vapor, W/(cm)(K)
ρ	D	density, g/cm ³
$ ho_{ extsf{L}}$	DL	density of saturated liquid, ${ m g/cm}^3$
$ ho_{\mathbf{V}}$	DV	density of saturated vapor, g/cm^3
$ ho_{\mathbf{a}}$	RHOA	constant used in Q-function, $\rho_a = 0.634$
$ ho_{f b}$	RHOB	constant used in Q-function, $\rho_{\rm b}$ = 1.0
σ	SIGMA	surface tension, dyne/cm
$\tau = \frac{1000}{T}$	TAU	temperature parameter, K ⁻¹

$^{ au}\mathrm{a}$	TAUA	constant used in Q-function, $\tau_a = 2.5$
$ au_{ m c}$	TAUC	1000 divided by critical temperature expressed in kelvin
ψ	PSI	Helmholtz free energy, $\rm J/g$
$\psi_{f 0}$	PSI0	reference function, J/g
$\frac{d\psi_0}{dT}$	PSIT	
$\left(rac{\partial \mathbf{Q}}{\partial au} ight)_{oldsymbol{ ho}}$	QTD	
$\left(rac{\partial \mathbf{Q}}{\partial oldsymbol{ ho}} ight)_{\! au}$	QDT	
$\left(\frac{\hat{c}^2\mathbf{Q}}{\partial \tau^2}\right)_{\!$	Q2T2D	partial derivatives used in evaluating ψ and its derivatives
$\left(rac{\partial^2 \mathbf{Q}}{\partial ho^2} \right)_{\!$	Q2D2T	
$\frac{\partial^{2}\mathbf{Q}}{\partial au \ \partial ho}$	Q2DT	

APPENDIX B

PROPERTY EQUATIONS OF WASP

The equations used in WASP were those taken from Keyes, Keenan, Hill, and Moore (ref. 3), Schmidt (ref. 2) and the ASME Steam Tables (ref. 1) and those developed by the authors.

FUNDAMENTAL EQUATION

The basic equation of WASP expresses the Helmholtz free energy in terms of ρ and T,

$$\psi = \psi(\rho, \mathbf{T}) \tag{B1}$$

whereas the equation of state is usually expressed as

$$P = P(\rho, T) \tag{B2}$$

Equation (B1) is complete inasmuch as the required thermodynamic functions are derivatives of ψ and undetermined constants and/or functions are not required. For example, specific heat at "zero" pressure C_{p_0} , which is a function of temperature, is not required in the ψ -form; however, in the P-form (eq. (B2)), C_{p_0} is required to obtain entropy, enthalpy, and specific heats.

When equation (B1) is expanded, ψ becomes

$$\psi = \psi_0(T) + RT[\ln \rho + \rho Q(\rho, \tau)]$$
 (B3)

where

$$Q = \sum_{i=1}^{8} A_{i1}(\rho - \rho_a)^{i-1} + e^{-E\rho}(A_{9,1} + A_{10,1}\rho)$$

$$+ (\tau - \tau_c) \left\{ \sum_{j=2}^{7} (\tau - \tau_a)^{j-2} \left[\sum_{i=1}^{8} A_{ij} (\rho - \rho_b)^{i-1} + e^{-E\rho} (A_{9j} + A_{10j}\rho) \right] \right\}$$
 (B4)

$$\psi_0(T) = C_1 + C_2 T + C_3 T^2 + (C_4 + C_5 T) \ln T$$
 (B5)

$$\tau = \frac{1000}{T} \,\mathrm{K}^{-1} \tag{B6}$$

$$\rho_{a} = 0.634 \text{ g/cm}^{3}$$

$$\rho_{b} = 1.0 \text{ g/cm}^{3}$$

$$\tau_{a} = 2.5 \text{ K}^{-1}$$

$$\tau_{c} = 1.544912 \text{ K}^{-1}$$

$$E = 4.8 \text{ cm}^{3}/\text{g}$$

$$R = 0.46151 \text{ J/(g)(K)}$$
(B7)

and the constants $\,C_{1},\,\ldots,\,C_{5}\,$ and $\,A_{ij}\,$ are given in table IV.

DERIVATIVES OF Q

The derivatives of Q are required to evaluate any of the thermodynamic properties:

$$\left(\frac{\partial Q}{\partial \tau}\right)_{\rho} = \left\{\sum_{j=2}^{7} (\tau - \tau_{a})^{j-2} \left[\sum_{i=1}^{8} A_{ij}(\rho - \rho_{b})^{i-1} + e^{-E\rho}(A_{9j} + A_{10j}\rho)\right]\right\}
+ (\tau - \tau_{c}) \left\{\sum_{j=3}^{7} (j-2)(\tau - \tau_{a})^{j-3} \left[\sum_{i=1}^{8} A_{ij}(\rho - \rho_{b})^{i-1} + e^{-E\rho}(A_{9j} + A_{10j}\rho)\right]\right\}$$
(B8)

$$\left(\frac{\partial Q}{\partial \rho}\right)_{\tau} = \sum_{i=2}^{8} (i - 1)A_{i1}(\rho - \rho_{a})^{i-2} + e^{-E\rho} \left[-E(A_{9, 1} + A_{10, 1}\rho) + A_{10, 1}\right]$$

$$+ (\tau - \tau_c) \left(\sum_{j=2}^{7} (\tau - \tau_a)^{j-2} \left\{ \sum_{i=2}^{8} (i - 1) A_{ij} (\rho - \rho_b)^{i-2} + e^{-E\rho} \left[- (A_{9j} + A_{10j}\rho)E + A_{10j} \right] \right\} \right)$$
(B9)

$$\frac{\partial^{2}Q}{\partial\rho\ \partial\tau} = \sum_{j=2}^{7} (\tau - \tau_{a})^{j-2} \left[\sum_{i=2}^{8} (i-1)A_{ij}(\rho - \rho_{b})^{i-2} + e^{-E\rho}(-EA_{9j} - E\rho A_{10j} + A_{10j}) \right]$$

$$+ (\tau - \tau_{c}) \left\{ \sum_{j=3}^{7} (j-2)(\tau - \tau_{a})^{j-3} \left[\sum_{i=2}^{8} (i-1)A_{ij}(\rho - \rho_{b})^{i-2} + e^{-E\rho}(-EA_{9j} - EA_{10j}\rho + A_{10j}) \right] \right\}$$
(B10)

$$\left(\frac{\partial^{2}Q}{\partial\rho^{2}}\right)_{\tau} = \sum_{i=3}^{8} A_{i1}(i-1)(i-2)(\rho-\rho_{a})^{i-3} + e^{-E\rho}\left\{\left[-EA_{9,1} + A_{10,1}(2-E\rho)\right](-E)\right\}$$

$$+ (\tau - \tau_c) \left(\sum_{j=2}^{7} (\tau - \tau_a)^{j-2} \left\{ \sum_{i=3}^{8} A_{ij} (i-1)(i-2)(\rho - \rho_b)^{i-3} + e^{-E\rho} \left[-EA_{9j} + A_{10j} (2 - E\rho) \right] (-E) \right\} \right)$$
(B11)

$$\begin{split} \left(\frac{\partial^{2}Q}{\partial\tau^{2}}\right)_{\rho} &= 2 \left\{ \sum_{j=3}^{7} (j-2)(\tau-\tau_{a})^{j-3} \left[\sum_{i=1}^{8} A_{ij}(\rho-\rho_{b})^{i-1} + e^{-E\rho}(A_{9j} + A_{10j}\rho) \right] \right\} \\ &+ (\tau-\tau_{c}) \left\{ \sum_{j=4}^{7} (j-2)(j-3)(\tau-\tau_{a})^{j-4} \left[\sum_{i=1}^{8} A_{ij}(\rho-\rho_{b})^{i-1} + e^{-E\rho}(A_{9j} + A_{10j}\rho) \right] \right\} \end{split} \tag{B12}$$

THERMODYNAMIC PROPERTIES

The derivatives of ψ give all the functions necessary to obtain the thermodynamic properties.

Pressure and Its Derivatives

$$\mathbf{P} = \rho^2 \left(\frac{\partial \psi}{\partial \rho}\right)_{\mathbf{T}} = \rho^2 \left(\frac{\partial \psi}{\partial \rho}\right)_{\tau} = \rho \mathbf{R} \frac{1000}{\tau} \left[1 + \rho \mathbf{Q} + \rho^2 \left(\frac{\partial \mathbf{Q}}{\partial \rho}\right)_{\tau}\right]$$
(B13)

$$\left(\frac{\partial \mathbf{P}}{\partial \rho}\right)_{\tau} = \frac{1000 \text{ R}}{\tau} \left[1 + 2\rho \mathbf{Q} + 4\rho^2 \left(\frac{\partial \mathbf{Q}}{\partial \rho}\right)_{\tau} + \rho^3 \left(\frac{\partial^2 \mathbf{Q}}{\partial \rho^2}\right)_{\tau} \right]$$
(B14)

$$\left(\frac{\partial \mathbf{P}}{\partial \tau}\right)_{\rho} = \frac{-1000}{\tau^2} \left(\rho \mathbf{R} \left[1 + \rho \mathbf{Q} + \rho^2 \left(\frac{\partial \mathbf{Q}}{\partial \rho} \right)_{\tau} \right] - \mathbf{R} \rho_{\tau} \left\{ \rho \left[\left(\rho \frac{\partial^2 \mathbf{Q}}{\partial \tau \partial \rho} \right) + \left(\frac{\partial \mathbf{Q}}{\partial \tau} \right)_{\rho} \right] \right\} \right)$$
(B15)

$$\left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\rho} = -\left(\frac{\partial \mathbf{P}}{\partial \tau}\right)_{\rho} \frac{\tau^2}{1000}$$
(B16)

Enthalpy and Its Derivatives

$$H = u + \frac{P}{\rho} \tag{B17}$$

$$\mathbf{H} = \left[\frac{\partial(\psi\tau)}{\partial\tau}\right]_{\rho} + \frac{\mathbf{P}}{\rho} \tag{B18}$$

$$H = \left[\psi_0 + 1000 \, R\rho \left(\frac{\partial Q}{\partial \tau} \right)_{\rho} - T \, \frac{d\psi_0}{dT} \right] + \frac{1000 \, R}{\tau} \left[1 + \rho Q + \rho^2 \left(\frac{\partial Q}{\partial \rho} \right)_{\tau} \right]$$
(B19)

where the first term of equation (B19) is the internal energy u.

$$H = \frac{1000 \text{ R}}{\tau} \left\{ 1 + \rho \left[Q + \tau \left(\frac{\partial Q}{\partial \tau} \right)_{\rho} + \rho \left(\frac{\partial Q}{\partial \rho} \right)_{\tau} \right] \right\} + \psi_{0} - T \frac{d\psi_{0}}{dT}$$
(B20)

$$\left(\frac{\partial H}{\partial T}\right)_{\rho} = -T \frac{d^{2}\psi_{0}}{dT^{2}} + R \left[1 + \rho Q + \rho^{2} \left(\frac{\partial Q}{\partial \rho}\right)_{\tau} - \tau \rho \left(\frac{\partial Q}{\partial \tau}\right)_{\rho} - \tau \rho^{2} \frac{\partial^{2} Q}{\partial \tau \partial \rho} - \rho \tau^{2} \left(\frac{\partial^{2} Q}{\partial \tau^{2}}\right)_{\rho}\right]$$
(B21)

$$\left(\frac{\partial \mathbf{H}}{\partial \rho}\right)_{\mathbf{T}} = \frac{1000 \ \mathbf{R}}{\tau} \left\{ \mathbf{Q} + \tau \left[\left(\frac{\partial \mathbf{Q}}{\partial \tau}\right)_{\rho} + \rho \frac{\partial^{2} \mathbf{Q}}{\partial \rho \ \partial \tau} \right] + \rho \left[3 \left(\frac{\partial \mathbf{Q}}{\partial \rho}\right)_{\tau} + \rho \left(\frac{\partial^{2} \mathbf{Q}}{\partial \rho^{2}}\right)_{\tau} \right] \right\} \tag{B22}$$

Entropy

$$S = -\left(\frac{\partial \psi}{\partial T}\right)_{\rho} \tag{B23}$$

$$S = -R \left\{ \ln \rho + \rho \left[Q - \tau \left(\frac{\partial Q}{\partial \tau} \right)_{\rho} \right] \right\} - \frac{d\psi_0}{dT}$$
(B24)

Specific Heats

Constant volume:

$$C_{\mathbf{v}} = \left(\frac{\partial \mathbf{u}}{\partial \mathbf{T}}\right)_{\rho} \tag{B25}$$

$$C_{v} = -\left[R\rho\tau^{2} \left(\frac{\partial^{2}Q}{\partial\tau^{2}}\right)_{\rho} + T \frac{d^{2}\psi_{0}}{dT^{2}}\right]$$
(B26)

Constant pressure:

$$C_{\mathbf{p}} = \left(\frac{\partial \mathbf{H}}{\partial \mathbf{T}}\right)_{\rho} - \left(\frac{\partial \mathbf{H}}{\partial \rho}\right)_{\mathbf{T}} \left[\frac{\left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\rho}}{\left(\frac{\partial \mathbf{P}}{\partial \rho}\right)_{\mathbf{T}}}\right]$$
(B27)

"Isentropic" expansion coefficient:

$$\gamma = \frac{C_p}{C_v}$$
 (B28)

Sonic Velocity

$$C^2 = \left(\frac{\partial \mathbf{P}}{\partial \rho}\right)_{\mathbf{S}} \tag{B29}$$

$$C^2 = \gamma \left(\frac{\partial P}{\partial \rho}\right)_T \tag{B30}$$

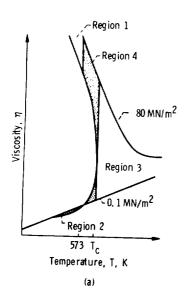
Vapor Pressure Curve

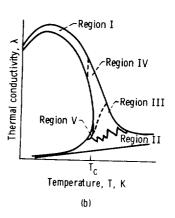
$$\log_{10} P = (1 + D_1) + \sum_{j=3}^{7} D_j (T - 273.15)^j + \frac{D_2}{T - 273.15}$$
 (B31)

where the original data are in bars and ^{O}C whereas pressure and temperature in the program are in MN/m^{2} and K, hence the forms (1 + D_{1}) and (T - 273.15).

TRANSPORT PROPERTIES

The transport property equations are not as concisely defined as the fundamental equation. The transport maps for viscosity and thermal conductivity are broken into several regions, as shown in sketches a and b, respectively, and individual curve fits are presented for each. Also, several regions are void of description as they exist in references 1 and 2.





Viscosity

Atmospheric pressure. - For $P = 0.1 \text{ MN/m}^2$ and 373.15 K < T < 973.15 K,

$$\eta_1 = \left[b_1 \left(\frac{T}{T_c} - b_2 \right) + b_3 \right] \times 10^{-6}$$
(B32)

Region 1. - For $P_{sat} < P < 80 \text{ MN/m}^2$ and 273. 15 K < T < 573. 15 K,

$$\eta = 10^{-6} a_1 \left[1 + \left(\frac{\rho}{\rho_c} - \frac{P_{sat}}{P_c} \right) \times a_4 \left(\frac{T}{T_c} - a_5 \right) \right] \times 10^{\left[\frac{a^2}{(T/T_c) - a_3} \right]}$$
(B33)

Region 2. - For 0.1 MN/m² < P < P $_{sat}$ and 373.15 K < T < 573.15 K,

$$\eta = \left\{ \eta_1 \times 10^6 - 10 \frac{\rho}{\rho_c} \left[c_1 - c_2 \left(\frac{T}{T_c} - c_3 \right) \right] \right\} \times 10^{-6}$$
(B34)

Region 3. - For 0.1 $MN/m^2 < P < 80 \ MN/m^2$ and 648.15 K < T < 1073.15 K,

$$\eta = \left[\eta_1 \times 10^6 + d_3 \left(\frac{\rho}{\rho_c} \right)^3 + d_2 \left(\frac{\rho}{\rho_c} \right)^2 + d_1 \left(\frac{\rho}{\rho_c} \right) \right] \times 10^{-6}$$
 (B35)

Region 4. - Tabulated values of viscosity in region 4, as well as computed values of viscosity at equivalent densities, were plotted as per figure 1. The resulting curve gives an accurate representation of these data, with the exception of those values along the saturation locus in the near-critical region. As can be seen, deviations of up to 7 percent, and 10 percent at the critical point, are common.

$$k = 1 for $\rho/\rho_c \le 4/3$

$$k = 2 for $\rho/\rho_c > 4/3$

$$(B36)$$$$$$

$$\eta = \eta_1 + \frac{10^{\mathrm{Y}}}{0.0192} \tag{B37}$$

where

$$Y = C_{5k}X^4 + C_{4k}X^3 + C_{3k}X^2 + C_{2k}X + C_{1k}$$
 (B38)

$$X = \log_{10} \left(\frac{\rho}{\rho_c} \right) \tag{B39}$$

The following coefficients are used in the viscosity equations:

$$a_1 = 241.4$$
 $c_1 = 586.1198738$ $a_2 = 0.3828209486$ $c_2 = 1204.753943$ $a_3 = 0.2162830218$ $c_3 = 0.4219836243$ $a_4 = 0.1498693949$ $a_5 = 0.4711880117$ $d_2 = 67.32080129$ $d_3 = 3.205147019$ $d_3 = 80.4$

$$C_{1k} = -6.4556581$$

$$C_{2k} = 1.3949436$$

$$C_{3k} = 0.30259083$$

$$C_{4k} = 0.10960682$$

$$C_{5k} = 0.015230031$$

For k = 2,

$$C_{1k} = -6.4608381$$

$$C_{2k} = 1.6163321$$

$$C_{3k} = 0.07097705$$

$$C_{4k} = -13.938$$

$$C_{5k} = 30.119832$$

Thermal Conductivity

Atmospheric pressure. - For $P = 0.1 \text{ MN/m}^2$ and 373.15 K < T < 973.15 K,

$$\lambda_1 = (17.6 + 0.0587 t + 1.04 \times 10^{-4} t^2 - 4.51 \times 10^{-8} t^3) \times 10^{-5}$$
 (B40)

where

$$t = T - 273.15$$
 (B41)

Region I. - For $P_{sat} < P < 50.0 \ MN/m^2$ and 273.15 K < T < 623.15 K,

$$\lambda = \left\{ S_1 + \left(\frac{P - P_{sat}}{P_c} \right) \left[S_2 + \left(\frac{P - P_{sat}}{P_c} \right) S_3 \right] \right\} \times 10^{-2}$$
(B42)

where

$$S_1 = \sum_{i=0}^4 a_i \left(\frac{T}{T_c}\right)^i$$
 (B43)

$$S_2 = \sum_{i=0}^{3} b_i \left(\frac{T}{T_c}\right)^i$$
 (B44)

$$S_3 = \sum_{i=0}^{3} c_i \left(\frac{T}{T_c}\right)^i$$
 (B45)

Region II. - For the following ranges of pressure (in MN/m^2) and temperature (in K):

$$0.1 < P \le 17.5$$
 and $T_{sat} < T < 973.15$
 $17.5 < P \le 22.5$ and $673.15 < T < 973.15$
 $22.5 < P \le 27.5$ and $698.15 < T < 973.15$
 $27.5 < P \le 35.0$ and $723.15 < T < 973.15$
 $35.0 < P \le 45.0$ and $773.15 < T < 973.15$
 $45.0 < P \le 50.0$ and $823.15 < T < 973.15$

thermal conductivity is

$$\lambda = \left[\lambda_1 + (103.51 + 0.4198 t - 2.771 \times 10^{-5} t^2) \rho + \frac{2.1482 \times 10^{14}}{t^{4.2}} \rho^2 \right] \times 10^{-5}$$
 (B46)

where

$$t = T - 273.15$$
 (B47)

Region III. - If the (P, T) is not in region II (see eq. (B54)) but $P < 50 \ MN/m^2$ and 373. 15 K < T < 973.15 K, then the following should be used:

$$\lambda = \frac{A\left(\frac{T}{T_{c}}\right)^{1.445}}{1 - Bd_{31}\left(\frac{T}{T_{c}}\right)^{-7}} + \frac{d_{32}\left(\frac{P}{P_{c}}\right)^{4} \exp\left[-9d_{33}\left(\frac{T}{T_{c}} - 1\right)\right]}{1 + d_{34}\left(\frac{P}{P_{c}}\right)^{-12}} \times \left\{d_{35} - d_{36}\left(\frac{P}{P_{c}}\right) \exp\left[-d_{33}\left(\frac{T}{T_{c}} - 1\right)\right]\right\}$$
(B48)

$$A = a_{31} \left(\frac{P}{P_C} \right) + a_{32} \tag{B49}$$

$$B = \frac{b_{31} \left(\frac{P}{P_{c}}\right)^{1.63}}{1 + b_{32} \left(\frac{P}{P_{c}}\right)^{3.26}}$$
(B50)

$$C = \frac{c_{31} \left(\frac{P}{P_{c}}\right)^{1.5} + c_{32}}{B} - c_{33}$$
 (B51)

Region IV. - If the (P, T) is not in region III (see eq. (B54)) but $P < 50 \text{ MN/m}^2$ and T > 623.15 K, then the following should be used:

$$\left(\frac{T}{T_c}\right) = \sum_{i=0}^{8} a_{4i} k^i + \left(\frac{P}{P_c} - c_{40}\right) \sum_{i=0}^{8} b_{4i} k^i$$
(B52)

where

$$k = 100 \lambda \tag{B53}$$

The solution for λ is iterative. And

$$\left(\frac{P}{P_c}\right) = \sum_{i=0}^{2} e_i \left(\frac{T}{T_c}\right)^i$$
 (B54)

is the boundary of region III-IV.

Region V. - In region V, tabulated values of thermal conductivity as well as computed values of thermal conductivity at equivalent densities were plotted as per figure 2. The resulting curve gives a good representation of the tabulated values, except along the saturation locus. However, deviations up to 8 percent, and 10 percent near critical, can be expected as listed in the table. These tabulated data and this curve fit do not include the anomalous behavior of thermal conductivity in the near-critical region.

$$k = 1$$
 for $\frac{\rho}{\rho_c} \le 2.5$ (B55)

$$\mathbf{k} = \mathbf{2}$$
 for $\frac{\rho}{\rho_{\mathbf{c}}} > 2.5$ (B56)

$$\lambda = \lambda_1 + 10^{\mathbf{Y}} \tag{B57}$$

where

$$Y = C_{5k}X^{4} + C_{4k}X^{3} + C_{3k}X^{2} + C_{2k}X + C_{1k}$$
(B58)

and

$$X = \log_{10} \left(\frac{\rho}{\rho_c} \right) \tag{B59}$$

The constants used in equation (B58) are as follows:

For
$$k = 1$$
,

$$C_{1k} = -0.5786154$$

$$C_{3k} = 0.17006978$$

$$C_{4k} = 0.1334805$$

$$C_{5k} = 0.032783991$$

For k = 2,

$$C_{1k} = -0.70859254$$

$$C_{2k} = 0.94131399$$

$$C_{3k} = 0.064264434$$

$$C_{4k} = 1.85363188$$

$$C_{5k} = 1.98065901$$

The following coefficients are used in the equations for thermal conductivity:

$b_0 = -0.20954276$
$b_1 = 1.320227345$
$b_2 = -2.485904388$
$b_3 = 1.517081933$
$b_{31} = 6.637426916 \times 10^5$
$b_{32} = 1.388806409$
$b_{40} = 1.514476538$
$b_{41} = -19.58487269$
$b_{42} = 113.6782784$

$a_{42} = 23.60292291$	$b_{43} = -327.0035653$
a ₄₃ = -51. 44066584	$b_{44} = 397.3645617$
$a_{44} = 38.86072609$	$b_{45} = 96.82365169$
$a_{45} = 33.47617334$	$b_{46} = -703.0682926$
$a_{46} = -101.0369288$	$b_{47} = 542.9942625$
$a_{47} = 101.2258396$	$b_{48} = -85.66878481$
a ₄₈ = -45.69066893	
$c_0 = 0.08104183147$	$d_{31} = 2.100200454 \times 10^{-6}$
$c_1 = -0.4513858027$	$d_{32} = 23.94$
$c_2 = 0.8057261332$	$d_{33} = 3.458$
$c_3 = -0.4668315566$	$d_{34} = 13.6323539$
$c_{31} = 3.388557894 \times 10^5$	$d_{35} = 0.0136$
$c_{32} = 576.8$	$d_{36} = 7.8526 \times 10^{-3}$
$c_{33} = 0.206$	50 60995706
$c_{40} = 1.017179024$	$e_1 = 50.60225796$
10	$e_2 = -105.6677634$
	$e_3 = 55.96905687$

Thermal Conductivity - Anomalous Region

The Senger technique (ref. 12) as modified in reference 13 and again herein is calculated for $0.4 \le \rho/\rho_{\rm C} \le 1.6$. Let

$$X^{\beta} = \left(\frac{\left|1 - \frac{T}{T_{c}}\right|}{\left|1 - \frac{\rho}{\rho_{c}}\right|^{1/0.35}}\right)^{0.35}$$

and $\lambda_{\mathbf{F}}$ represent the nonanomalous or frozen thermal conductivity. For $\mathbf{X}^{\beta} < 0.4$,

$$\lambda - \lambda_{\mathbf{F}} = \frac{11.6 \times 10^{-5}}{\sqrt{\frac{\rho}{\rho_{\mathbf{c}}}} \left| 1 - \frac{\rho}{\rho_{\mathbf{c}}} \right|^{1.71}}$$
(B60)

For $X^{\beta} > 3$,

$$\lambda - \lambda_{\mathbf{F}} = \frac{11.6 \times 10^{-5}}{\sqrt{\frac{\rho}{\rho_{c}}} \left| 1 - \frac{\mathbf{T}}{T_{c}} \right|^{0.6}}$$
(B61)

For $0.4 \le X^{\beta} \le 3$,

$$\lambda - \lambda_{\mathbf{F}} = \frac{11.6 \times 10^{-5} \ 10^{X_0}}{\sqrt{\frac{\rho}{\rho_c}} \left| 1 - \frac{T}{T_c} \right|^{0.6}}$$
(B62)

where

$$X_0 = \sum_{i=0}^{4} a_i \zeta^i \tag{B63}$$

$$\zeta = \log_{10} X^{\beta}$$

and

$$a_0 = -0.17384732$$

$$a_1 = 0.82350372$$

$$a_2 = -1.55213983$$

$$a_3 = -0.12626138$$

$$a_4 = 2.83922425$$

Surface Tension and the Laplace Constant

Surface tension is given by

$$\sigma = \frac{a_1(T - T_c)^2}{1 - 0.83(T - T_c)} + \sum_{i=2}^{5} a_i(T - T_c)^i$$
(B64)

where

$$a_1 = 0.1160936807$$
 $a_2 = 1.121404688 \times 10^{-3}$
 $a_3 = 5.75280518 \times 10^{-6}$
 $a_4 = 1.28627465 \times 10^{-8}$
 $a_5 = 1.149719240 \times 10^{-11}$

The Laplace constant is

$$L = \sqrt{\frac{\sigma}{g(\rho_L - \rho_V)}}$$
 (B65)

where g is the local acceleration. If g is the acceleration of gravity,

$$g = 980.665 \text{ cm/sec}^2$$
 (B66)

APPENDIX C

DESCRIPTION OF IMPORTANT SUBROUTINES IN WASP

This appendix includes a discussion of the input/output and important features of the major subroutines in WASP. The method of solution used for the equations is indicated. The equation numbers refer to equations presented in appendix B. The FORTRAN IV variables mentioned correspond to the program listing in appendix E. The shorter subroutines not included in appendix C are completely described by comments in the listing in appendix E. Subroutine WASP has been described in the main text, in tables I and II; hence, the reader is assumed to be familiar with subroutine WASP.

MATHEMATICAL ROUTINES

The mathematical routines are as follows:

- (1) Function SOLVE (X1, F, DF): This routine performs a Newton-Raphson iteration given the initial estimate X1, the function F, and the derivative function DF. The convergence is determined when $|(X_N X_{N-1})/X_N| < TOL$. The value of TOL is 1. E-5 for iterations 1 to 40, 1. E-4 for 41 to 60, 1. E-3 for 61 to 80, and 1. E-2 for 81 to 100. In all cases studied the convergence was usually obtained in fewer than 40 iterations. For the exceptions, usually in the near-critical region of the PVT surface, the values returned with the increased tolerance are the best obtainable using equation (B3). The maximum number of iterations is 100, and an appropriate message is written if this number is reached.
- (2) Subroutines ROOT (X0, X2, FOFX, FUNC, X1) and ROOTX (X0, X2, FOFX, FUNC, X1): These two routines are identical except for name. The duplication is necessary for the double iterations in the solutions for temperature and density given pressure and enthalpy (KS=4) or pressure and entropy (KS=5) as input. (See also table I.)

The solution method is a modified half-interval search technique for a monotonic function, FUNC, with a root between X0 and X2 such that FUNC(X1) = FOFX where X1 is the answer returned. The number of iterations does not exceed 100, and the tolerance is varied in the same manner as in function SOLVE. In addition, both the root and the function value FUNC(X1) must meet a tolerance. While the tolerance on X1 is TOL, the tolerance on FUNC(X1) is 10*TOL. Error messages are written when the iterations reach 100 or when there is no solution in the interval X0 to X2.

Q-FUNCTIONS

These routines use D and TAU in program units of KU=1. Entry points with TAU as input indicate an iteration where D is known, while entry points with D and TAU as input are used in solving for D and in calculating all derived properties.

The Q-functions are as follows:

- (1) Function QMUST(D) calculates summation terms involving D needed by other Q-functions and stores them in COMMON/QAUX/ and /QSI/. ENTRY QMUST2(TAU) calculates summation terms involving TAU and stores them in /QAUX/.
 - (2) Function QCALC(TAU) calculates equation (B4).
 - (3) Function QTD(TAU) calculates equation (B8).
 - (4) Function QDTA(TAU) and ENTRY QDT(D, TAU) calculate equation (B9).
 - (5) Function Q2DTA(TAU) and ENTRY Q2DT(D, TAU) calculate equation (B10).
 - (6) Function Q2D2TA(TAU) and ENTRY Q2D2T(D, TAU) calculate equation (B11).
 - (7) Function Q2T2D(TAU) calculates equation (B12).

FUNCTION CHECK

Function CHECK includes

- (1) ENTRY TCHECK (KU, KR, T)
- (2) ENTRY PCHECK (KU, KR, P)
- (3) ENTRY DCHECK (KU, D)

These entry points convert the variables from the user's units to the program's units, represented by KU=1, and check for out-of-range variables. Appropriate messages are written for any out-of-range input, but the calculation is allowed to continue.

The following subroutines use the mathematical routines, the Q-functions, function CHECK, and the subroutines listed with each in table V. The use of these subroutines is determined by the KS and KP options (see table I) and are called by subroutine WASP. If a user wants to use only a few of these subroutines, he can disassemble the WASP program by following the instructions in appendix D and the discussion for the routine of interest. Subroutine WASP uses the temperature parameter TAU (in user's units) for input to the subroutines. All the derived thermodynamic property and transport property subroutines assume that TAU, P, and D have been previously calculated. These subroutines are called twice by WASP for saturation properties, once with DL and once with DV as input for D.

SUBROUTINES TO OBTAIN STATE VARIABLES (KS OPTIONS)

The subroutines used to obtain the state variables are as follows:

(1) Subroutine DENS (KU, TAU, P, D, DL, DV, KR): This routine solves equation (B13) for the density, given TAU and P in units indicated by KU. The region number (KR) is returned, and the density is returned in D for KR=2 or KR=3. For KR=1, the saturation values are returned in DL and DV. If KR=1 for input and either TAU=0 or P=0 for input, the saturated value is calculated and returned for the variable which was input as 0.

The solution is obtained by ROOT for subcritical pressures and by SOLVE for saturation or supercritical pressures. Special initial estimates were found necessary for convergence near subcritical temperatures with SOLVE and for the interval used by ROOT in the region $P>P_c$ and 373.15 K < T < 453.15 K (100° C < t < 180° C).

- (2) Subroutine PRESS (KU, TAU, D, P, KR): This routine calculates pressure (eq. (B13)) as a function of TAU and D in regions KR=2 and KR=3 and as a function of TAU only in region KR=1 (using subroutine PSSS). The result, P, is returned in user's units indicated by KU. The correct value of KR is also returned and the calculation is direct.
- (3) Subroutine TEMP (KU, P, D, TAU, KR): This routine solves equation (B13) for the temperature parameter TAU, given P and D in user's units specified by KU. In regions KR=2 and KR=3, SOLVE is used to obtain the solution. In region KR=1, which is either input or determined, TAU is a function of P only and is obtained from subroutine TSS by solving equation (B31) for TAU. Subroutine TSS also uses SOLVE. The correct KR is returned.
- (4) Subroutine TEMPPH (KU, P, H, TAU, D, DL, DV, KR): This routine solves equation (B13) by using equation (B20) for the temperature parameter TAU and density D, given P and H as input in user's units indicated by KU. The double iteration is performed by using ROOT and ROOTX with function TSHF for regions KR=2 and KR=3. In region KR=1, the saturation values are determined for DL and DV by DENS, and TAU is found by function TSS (using SOLVE). KR is also returned.
- (5) Subroutine TEMPPS (KU, P, S, TAU, D, DL, DV, KR): This routine solves equations (B13) and (B24) for TAU and D in the same manner as TEMPPH, using P and S as input and function TPSF for the double iteration with ROOT and ROOTX.

SUBROUTINES TO OBTAIN DERIVED THERMODYNAMIC PROPERTIES

The subroutines used to obtain derived thermodynamic properties assume that the variables TAU and D have been input or previously calculated in the user's units. This condition is satisfied in subroutine WASP. When KR=1 is input or has been so deter-

mined, subroutine WASP makes two calls to each routine, once using DL and once DV for input D; and the corresponding saturated variable is output [(HL, SL, etc.), (HV, SV, etc.)].

These subroutines are as follows:

- (1) Subroutine ENTH (KU, TAU, D, H): This routine calculates enthalpy H in user's units (KU) by using equation (B20).
- (2) Subroutine ENT (KU, TAU, D, S): This routine calculates entropy S in user's units (KU) by using equation (B24).
- (3) Subroutine CPPRL (KU, TAU, D, CP, CV, GAMMA, C): This routine calculates the following in user's units indicated by KU:
 - (a) Specific heat at constant pressure, CP, eq. (B27)
 - (b) Specific heat at constant volume, CV, eq. (B26)
 - (c) Specific-heat ratio, GAMMA, eq. (B28)
 - (d) Sonic velocity, C, eq. (B30)

In addition, the first partial derivatives of P are calculated and returned in COMMON/PARTLS/PTV, PDT in the units of KU=1 only. PTV is equation (B16) and PDT is equation (B14).

SUBROUTINES TO OBTAIN TRANSPORT PROPERTIES

The three routines used to obtain the transport properties assume that the input variables for pressure and density and the temperature parameter τ are all available in user's units. They are called twice by WASP for saturation conditions, once with DL and once with DV as input for density DIN.

- (1) Subroutine VISC (KU, KR, TIN, PIN, DIN, SVISC): This routine uses TIN, PIN, and DIN as input in user's units KU. Dynamic viscosity, SVISC, is calculated by using one or more of equations (B32) to (B39), depending on the region of the input variables as shown in figure 1 and explained in appendix B. All calculations of dynamic viscosity are direct evaluations of curve fits.
- (2) Subroutine THERM (KU, KR, TIN, PIN, DIN, EXCESK, TCOND): This routine uses TIN, PIN, and DIN in user's units KU to calculate the thermal conductivity TCOND in user's units KU. An optional coding section calculates the critical excess thermal conductivity associated with the critical anomaly in the PVT region, $0.6 < \rho/\rho_{\rm c} < 1.4$ and $0.9 < T/T_{\rm c} < 1.1$. See also references 12, 13, and 15 and the subroutine listing in appendix E.

The equations used for thermal conductivity are (B40) to (B59) for the different regions as shown in figure 2. The equation for region IV $(e\varsigma. (B52))$ is iterative. The thermal conductivity for the other regions is calculated by direct evaluation of curve fits.

(3) Subroutine SURF (KU, KR, TIN, SURFT): This routine uses TIN, the input temperature parameter, in user's units, to calculate both the surface tension of liquid water and the Laplace constant. The calculated surface tension is returned in SURFT, and the Laplace constant (ALC) is returned in COMMON/LAPLAC/ALC. The statement COMMON/LAPLAC/ALC must appear in the user's calling routine if the Laplace constant is desired.

APPENDIX D

MODULAR DESIGN OF WASP

A user with limited core storage or with specific property needs may wish to use only parts of WASP. The subroutines have been coded so that most of the subroutines corresponding to the "KP option" requests may be removed without causing errors in logic or calculations. Table V indicates which routines are absolutely necessary and which are optional. The conditions for removal must be strictly followed. For simplicity, the KP options are discussed as though only one option was being requested. In reality, the input variable KP is always the summation of the KP option variables. To modify a statement number in subroutine WASP, simply replace it with a continue statement of the same number. For example, to remove the viscosity option, remove subroutine VISC. In subroutine WASP, alteration would read as follows:

160 CONTINUE170 DO175 I=1, 32

If the user wishes to omit many options, he should rewrite subroutine WASP for efficiency.

APPENDIX E

PROGRAM LISTING AND FLOW CHART FOR SUBROUTINE WASP

PROGRAM LISTING

```
SIBFIC ACUA
      SUBROUTINE WASP (KS.KP.TT.P.D.H.KR)
C KEYFS KENNAN HILL MOORE EQUATION OF STATE FOR WATER
        C
(
        COMPUTE THE STATE RELATIONS AND THERMODYNAMIC AND TRANSPORT
(
         PROPERTIES OF WATER GIVEN TEMPERATURE TT. PRESSURE P.
C
         DENSITY D. OR ENTHALPY H. OR ENTROPY S. STATE RELATIONS ARE
C
                                                                             7
         SPECIFIED BY KS. THERMODYNAMIC AND TRANSPORT PROPERTIES
C
C
         ARE SPECIFIED BY KP. IF KR IS RETURNED OR SPECIFIED AS 1.
                                                                             9
(
         PROPERTIES ARE COMPUTED AT SATURATION.
                                                                            10
C
                                                                            11
      COMMON/PROPTY/KU-DL.DV.HL.HV.S.SL.SV.CV.CVL.CVV.CP.CPL.CPV.GAMMA.
                                                                            12
     1GAMMAL .GAMMAV.C.CL.CVP.MU.MUL.MUV.K.KL.KV.SIGMA.EXCL.EXCV.EXCESK
                                                                            13
      REAL MU.MUL.MUV.K.KL.KV
                                                                            14
      COMMON/CHECKS/DCH1. DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.H
                                                                            15
     1SCH1.HSCH2
                                                                            16
C
                                                                            17
                                                                            18
C
    TAU IS THE TEMPERATURE PARAMETER USED IN THE EQUATION OF STATE
                                                                            19
ί
            TAU IS EQUIVALENT TO T IN THIS SUBROUTINE
                                                                            20
ſ
                                                                            21
C
                                                                            22
     DIFFNSICN KPC1(32). KPC2(32). KPC3(32).KPC4(32)
                                                                            23
      DATA KPC1 /2.3.6.7.10.11.14.15.18.19.22.23.26.27.30.31.34.35.38.
                                                                            24
     139.42.43.46.47.50.51.54.55.58.59.62.63/
                                                                            25
     DATA KPC2 /4.5.6.7.12.13.14.15.20.21.22.23.28.29.30.31.36.37.38.
                                                                            26
     139.44.45.46.47.52.53.54.55.60.61.62.63/
                                                                            27
     DATA KPC3 /8.9.10.11.12.13.14.15.24.25.26.27.28.29.30.31.40.41.42.
                                                                            28
    143.44.45.46.55.56.57.58.59.60.61.62.63/
                                                                            29
     DATA KPC4 /16.17.18.19.20.21.22.23.24.25.26.27.28.29.30.31.
                                                                            30
     148,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63/
                                                                            31
     T=TT
                                                                            32
       IF (TT.GT.O.) T=1000./TT
                                                                            33
     GG TO (10.20.30.40.45).KS
                                                                            34
C
                                                                            35
C
        COMPUTE DENSITY
                                                                            36
                                                                            37
   10 CALL DENS(KU.T.P.D.DL.DV.KR)
                                                                            38
     IF ( TT .EQ. 0.0) TT=1000./T
                                                                            39
     GO TO 50
                                                                            40
(
                                                                            41
```

```
C.
          COMPUTE PRESSURE
                                                                                    42
                                                                                    43
   20 CALL PRESS(KU.T.D.P.KR)
                                                                                    44
      GO TO 50
                                                                                    45
C
                                                                                    46
C
          COMPUTE TEMPERATURE
                                                                                    47
C
                                                                                    48
   30 CALL TEMP(KU.P.D.T.KR)
                                                                                    49
      TT=1000./T
                                                                                    50
      GO TO 50
                                                                                    51
C
                                                                                    52
C
          COMPUTE TEMPERATURE AND DENSITY GIVEN PRESSURE AND ENTHALPY
                                                                                    53
C
                                                                                    54
   40 CALL TEMPPH(KU.P.H.T.D.DL.DV.KR)
                                                                                    55
      TT=1000./T
                                                                                   56
      GO TO 50
                                                                                    57
   45 CALL TEMPPS ( KU.P.S.T.D.DL.DV.KR )
                                                                                    58
      TT=1000./T
                                                                                    59
   50 [F (KR.NE-1-OR-(KS.EQ-1-OR-KS-GT-3)) GO TO 55
                                                                                   60
                                                                                   61
   OBTAIN SATURATION DENSITIES DL AND DV FOR KS=2 AND KS=3 CALLS WHEN
C
                                                                                   62
C
     KR=1
                                                                                   63
C
                                                                                   64
      CALL DENS(KU.T.P.D.DL.DV.1)
                                                                                   65
   55 IF (MOD(KP.2))60,70,60
                                                                                   66
C
                                                                                   67
C
         COMPUTE ENTHALPY
                                                                                   68
C
                                                                                   69
   60 IF (KR.EQ.1) GO TO 65
                                                                                   70
      CALL ENTH(KU.T.O.H)
                                                                                   71
      GO TO 70
                                                                                   72
   65 CALL ENTH(KU.T.DL.HL)
                                                                                   73
      CALL ENTH (KU.T.DV.HV)
                                                                                   74
   70 DO 80 I=1.32
                                                                                   75
      IF (KP-KPC1(I))110,100,80
                                                                                   76
   80 CONTINUE
                                                                                   77
      GO TO 110
                                                                                   78
C
                                                                                   79
C
         COMPUTE ENTROPY
                                                                                   80
C
                                                                                   81
  100 IF (KR-EQ-1) GO TO 105
                                                                                   82
      CALL ENT(KU.T.D.S)
                                                                                   83
      GO TO 110
                                                                                   84
  105 CALL ENT (KU.T.DL.SL)
                                                                                   85
      CALL ENTIKU.T.DV.SV)
                                                                                   86
  110 00 120 I=1.32
                                                                                   87
      IF(KP-KPC2(I)) 140.130.120
                                                                                   88
  120 CONTINUE
                                                                                   89
      GO TO 140
                                                                                   90
C
                                                                                   91
C
         COMPUTE SPECIFIC HEATS AND GAMMA AND SONIC VELOCITY
                                                                                   92
C
                                                                                   93
 130 IF (KR.NE.1) GO TO 135
                                                                                   94
      CALL CPPRL(KU.T.DL.CPL,CVL.GANHAL.CL)
                                                                                   95
      CALL CPPRL(KU.T.DV.CPV.CVV.GAMMAV.CVP)
                                                                                   96
      GO TO 140
                                                                                   97
  135 CALL CPPRL(KU, T.D.CP.CV.GAMMA.C)
                                                                                   98
  140 00 150 [=1.32
                                                                                   99
      IF (KP-KPC3(I)) 170.160.150
                                                                                  1 ))
  150 CONTINUE
                                                                                  101
      GO TO 170
                                                                                  102
C
                                                                                  103
```

C	40.11 015 413C03114	
C		104
	160 IF (KR.NE.1) GO TO 165	105
	CALL VISCIKUAKRATAPADI ANULA	106
	CALL VISCIKU-KR.T.P.DV.MUV)	107
	GO TO 170	108
	165 CALL VISC(KU.KR.T.P.D.MU)	109
	170 00 175 I=1,32	110
	[F(KP-KPC4([)) 190,180,175	111
	175 CONTINUE	112
	GO TO 190	113
C		114
C	COMPUTE THERMAL CONDUCTIVITY	115
Ċ	AND OLD INCHASE COMPOCITATIA	116
_	180 IF (KR.NE.1) GO TO 220	117
	CALL THERM (KU.KR.P.T.DL.EXCL.KL)	118
	CALL THERM AND NO TOUR GROUP	119
	CALL THERM (KU.KR.P.T.DV.EXCV.KV) GC TO 190	120
		121
	220 CALL THERM (KU.KR.P.T.D.EXCESK.K)	122
C	190 [F(KP-32) 230,240,240	123
Ċ	COMPUTE CURE OF THE PROPERTY	124
C	COMPUTE SURFACE TENSION	125
L	240 CALL CURE LYLL UP T ARROWS	126
	240 CALL SURF (KU.KR.T.SIGMA)	127
	230 RETURN	128
	END	1 20

```
SIBFTC BLGC
      BLCCK CATA
                          ------VERSION MARCH 1,1972------
                                                                                 2
C
      DIMENSION A1(10).A2(10).A3(10).A4(10).A5(10).A6(10).A7(10)
      EQUIVALENCE (A1(1).A(1.1)).(A2(1).A(1.2)).(A3(1).A(1.3)).(A4(1).A(
     11.4)).(A5(1).A(1.5)).(A6(1).A(1.6)).(A7(1).A(1.7))
                                                                                 5
      COMMON /CODE/ MESSAG(16)
                                                                                 6
                                                                                 7
      CCHMON /COF/ A(10.7)
                                                                                 8
      COMMON /CRIT/ RHOCRT.PCRT.TCRT
                                                                                 9
      COMMON /CCNSTS/ TAUC.RHOA.RHOB.TAUA.E .R
      CGMMON/CHECKS/DCH1.DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.
                                                                                10
                                                                                11
     1HSCH1.HSCH2
                                                                                12
C
                                                                                13
      COMMON/COSAT/CPS1. CPS2.CPS3.CPS4.CPS5.CPS6.CPS7
                                                                                14
      COMMON /SICOF/ SIC1.SIC2.SIC3.SIC4.SIC5
                                                                                15
      COMMON /CONVI/DCONV(5)
      COMMON /CONV2/TCONV(5)
                                                                                 16
      CCMMON /CONV3/PCONV(5)
                                                                                17
                                                                                18
      COMMON/CONV4/SCONV(5)
                                                                                19
      COMMON/CGNV5/CCONV(5)
                                                                                20
      COMMON/CONV6/HCONV(5)
                                                                                21
      COMMON/CONV7/MCONV(5)
                                                                                 22
      COMMON/CONV8/KCONV(5)
                                                                                 23
      COMMON/CONV9/STCONV(5)
                                                                                24
      REAL MCONV.KCONV
      DATA A1/29.492937.-132.13917.274.64632.-360.93828.342.18431.
                                                                                25
     1 -244-50042, 155-18535, 5-9728487, -410-30848, -416-05860 /
                                                                                26
      DATA A2/ -5.1985860. 7.7779182. -33.301902. -16.254622.-177.31074.
                                                                                 27
     1127.48742. 137.46153. 155.57836. 337.31180. -209.88866
                                                                                28
                                                                                29
      DATA A3/ 6.8335354. -26.149751. 65.326396. -26.181978. 4*0.,
                                                                                30
     1-137.46618. -733.96848 /
                                                                                 31
      DATA A4/ -.1564104. -.72546108. -9.2734289. 4.312584. 4*0..
                                                                                 32
     1 6.7874983. 10.401717 /
      DATA A5/ -6.3972405, 26.409282, -47.740374, 56.32313, 4*0.,
                                                                                 33
                                                                                 34
     1 136.87317. 645.8188 /
                                                                                 35
      DATA 46/ -3.9661401, 15.453061, -29.14247, 29.568796, 4*0.,
                                                                                 36
     1 79.84797. 399.1757
      DATA A7/ --69048554, 2-7407416, -5-102807, 3-9636085, 4*0-,
                                                                                 37
                                                                                 38
     1 13.041253. 71.531353 /
      DATA CPS1.CPS2.CPS3.CPS4.CPS5.CPS6.CPS7/
                                                                                 39
           0.29304370E+01. -0.23095789E+04.
                                                    0.34522497E-01.
                                                                                 40
                                                                                 41
            -.13621289E-03.
                                0.25878044E-06.
                                                    --24709162E-09,
                                                                                 42
             0.95937646E-13
      DATA DCH1, DCH2, PCH1, PCH2, PCH3, TCH1, TCH2, TCH3, DST, TST,
                                                                                 43
     1HSCH1.HSCH2/0..1.04539..000611.22.089.100...55555556.1.544912.
                                                                                 44
                                                                                 45
     1 3.660900 ..8.400.....4700. /
      DATA MESSAG / 96H THERMODYNAMIC AND TRANSPORT PROPERTIES FOR WATER
                                                                                 46
                                                                                 47
     1PC=218.07ATM.TC= 647.29 K.ROC=.317 G/CC
                                                                                 48
      DATA RHOCRT.PCRT.TCRT/-317. 22-089. 641-286
      DATA SIC1.SIC2.SIC3.SIC4.SIC5/1855.3865. 3.278642.
                                                                                 49
      1-0.00037903. 46.174. -1.02117 /
                                                                                 50
      DATA TAUC.RHOA.RHOB.TAUA.E.R/ 1.544912, .634. 1., 2.5, 4.8, .46151/
                                                                                 51
                                                                                 52
      DATA TCCNV /1..1...55555555 .2*1.0 /
      DATA PCCNV/1-,9-8692327-145-038243-2*1-/
                                                                                 53
                                                                                 54
      DATA DCGNV/2+1 - . 62 - 4283 - 2+1 - /
                                                                                 55
      DATA SCONV/2*1..0.238849.2*1./
                                                                                 56
      DATA CCONV/2+1..0.03281.2+1./
      DATA HCCNV/2+1..0.429929.2+1./
                                                                                 57
                                                                                 58
      DATA MCGNV/2+1.0..67156899E-1.2+1.0/
                                                                                 59
      DATA KCCNV/2+1.E-2.1.6G6044E-4.2+1.E-2/
                                                                                 60
      DATA STCONV/ 2*1..6.8521766E-5.2*1./
                                                                                 61
      COPMON/XMINUS/XMI(7)
                                                                                 62
      DATA XM1/1 .. 2 . . 3 . . 4 . . 5 . . 6 . . 7 . /
                                                                                 63
       END
```

59

```
SIRFIC RGOT2
      SUBROUTINE ROOT (XO.X2.FOFX.FUNC.X1)
                             -----VERSION 2/1/72----
C
       SAME AS ROOTX - NEEDED TO PREVENT RECURSION
€
         SOLVE FOR X1 SUCH THAT FUNC(X1) = FOFX. WHERE X1 LIES
         BETWEEN XO AND X2
                                                                                     7
ſ
                                                                                     8
      COMMON /CHECKI/KOUNT
                                                                                     a
      TOL=1.E-5
                                                                                    10
      XXC = XC
                                                                                    11
      xx2 = x2
                                                                                    12
      FO = FUNC(XXO)
                                                                                    13
      F2 = FUNC(XX2)
                                                                                    14
      A=(F0FX-F0)/(F2-F0)
                                                                                    15
      IF (A) 1007.120.120
                                                                                    16
  120 IF (A-1.) 130.130.1008
                                                                                    17
  130 IF (FOFX-0.) 80.70.80
                                                                                    18
   70 ASSIGN 100 TO JUMP
                                                                                    19
      GO TO 90
                                                                                    20
   80 ASSIGN 110 TO JUMP
                                                                                    21
   90 \times = (\times \times 0 + \times \times 2)/2
                                                                                    22
      KOUNT = 0
                                                                                    23
  150 X1 = X
                                                                                    24
      KOUNT = KOUNT + 1
                                                                                    25
       A = FOFX - F2
                                                                                    26
      FX = FUNC(X)
                                                                                    27
       FXL=F0+(X-XX0)+(F2-F0)/(XX2-XX0)
                                                                                    28
       B=ABS((FX-FXL)/(F2-F0))
                                                                                    29
       IF (A*(FX-FOFX) .LT. 0.) GO TO 1001
                                                                                    30
       x = 0xx
                                                                                     31
       FO=FX
                                                                                     32
       IF (B--3) 10.20.20
                                                                                     33
    20 \times = (x + x \times 2)/2
                                                                                     34
       60 TO 40
                                                                                     35
  1001 XX2 = X
                                                                                     36
       F2 = FX
                                                                                     37
       IF (8-.3) 10.30.30
                                                                                     38
    30 \times = (\times \times 0 + \times)/2
                                                                                     39
       GO TO 40
                                                                                     40
    1C X=XX0+(FCFX-F0)+(XX2-XX0)/(F2-F0)
                                                                                     41
    40 IF (A8S((X-X1)/X)-TOL ) 50.1000.1000
                                                                                     42
    50 GO TO JUMP+(100+110)
                                                                                     43
   100 IF (ABS(FUNC(X))-TGL+10. )60,1000.1000
                                                                                     44
   110 IF (ABS((FOFX-FUNC(X))/FOFX)-TOL ) 60,1000,1000
                                                                                     45
  1000 IF (KOUNT.GT.40) TOL=TCL+10.
                                                                                     46
       IF (KOUNT.GT.60) TOL=TOL+10.
                                                                                     47
       IF (KOUNT.GT.80) TOL-TOL+10.
                                                                                     48
       IF (KOUNT-LT-100) GO TO 150
                                                                                     49
   16C WRITE (6.170) X1.X
   170 FORMAT (1HL.79HAN ITERATION HAS BEEN TERMINATED AT 100 ITERATIONS.
                                                                                     50
                                                                                     51
      1 THE LAST THO VALUES WERE +3G15+5)
                                                                                     52
    6C X1=X
                                                                                     53
       RETURN
                                                                                     54
  1007 \times 1 = \times 0
                                                                                     55
       GO TO 140
                                                                                      56
  1008 \times 1 = \times 2
                                                                                      57
   140 WRITE(6.141)
                                                                                      58
   141 FORMAT(1HO.24H SOLUTION OUT OF RANGE
                                                )
                                                                                      59
        RETURN
                                                                                      60
        ENC
```

3 14 C	FTC SCLV	
·	FUNCTION SOLVE(XI.F.DF)	1
c	TOTAL SULVEYALIFIUM	2
Č	NEWTON-RAPHSON ITERATION GIVEN AN INITIAL ESTIMATE XI	3
Č	AND THE FUNCTIONS F AND DE	4
-	COMMON /CHECKI/NI	5
	TOL=1.E-5	6
	NI=0	7
	X=0X	8
	XN=XI	9
	10 X00=X0	10
	XG=XN	11
	XN=XO-F(XO)/DF(XO)	12
	NI=NI+1	13
	1F (ABS((XN-XO)/XN)-TOL) 70.20.20	14
	20 IF (NI-GT-40) TOL=TOL+10.	15
	IF (NI-GT-60) TOL=TOL+10.	16
	IF (NI.GT.80) TGL=TOL+10.	17
	IF (NI-100) 30,50,50	18
	30 [F (ABS((XN-X00)/XN)-TOL) 40.10.10	19
	4C XN=(XO+XN)/2.	20
	GC TO 10	21
	50 WRITE (6.60) XOO, XO, XN	22
	60 FORMAT (1HL.81HAN ITERATION HAS BEEN TERMINATED AT 100 ITERATIONS.	23
	I THE LAST THREE VALUES HERE .3G15.5)	24
	70 SOLVE=XN	25
	RETURN	26
	END	27
	LITU	20

```
SIBFTC SCHEC
                CHECK(KU-KR-T)
     FUNCT LON
•
                  C
C
                                                                               5
     COMMON/CONVI/DCONV(5)
                                                                               6
     COMMON/CONV2/TCONV(5)
                                                                               7
     CCMMON/CONV3/PCONV(5)
                                                                               8
     COMMON/IERROR/ IROUT
     COMMON/CHECKS/DCH1.DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.
                                                                               9
                                                                              10
     1HSCH1.FSCH2
     DIMENSION FM1(9), FM2(9), FM3(9), FMT(9), ROUT(11)
                                                                              11
     DATA FM1 /51H(1H .G12.4 ,31HIS OUT OF RANGE FOR T IN SUB.-. A6 )
                                                                              12
                                                                              13
     1/
      DATA FM2 /51H(1H .G12.4 .31HIS OUT OF RANGE FOR P IN SUB.-. A6 )
                                                                              14
                                                                              15
     1 /
     DATA FM3 /51H(1H .G12.4 .31HIS OUT OF RANGE FOR D IN SUB.-. A6 )
                                                                              16
                                                                              17
      DATA ROUT /4HDENS.5HPRESS.4HTEMP .4HENTH, 3HENT .6HTEMPPH.6HTEMPPS
                                                                              18
                                                                              19
     1.5HCPPRL.4HVISC.5HTHERM.4HSURF/
                                                                              20
C
                                                                              21
         CONVERT TEMPERATURE T TO DEGREES KELVIN AND CHECK
C
         FOR OUT OF RANGE. UNITS ARE SPECIFIED BY KU. IF KR
                                                                              22
C
                                                                              23
         IS SPECIFIED AS 1. T IS CHECKED FOR OUT OF SATURATION
C
                                                                              24
         RANGE.
C
                                                                              25
                                                                              26
      ENTRY TCHECK (KU, KR, T)
                                                                              27
      CHECK=1000.+TCONV(KU)/T
                                                                              28
      CH1=1000 . / TCH3
                                                                               29
      CH2=1000-/TCH2
                                                                               30
      CH3=1000-/TCH1
                                                                               31
      KODE=1
                                                                               32
      DC 1 J=1.9
                                                                              33
    1 FMT(J)=FM1(J)
                                                                               34
      GO TO 10
                                                                               35
C
                                                                               36
          CONVERT PRESSURE TO MN/M**2 AND CHECK
         FOR OUT OF RANGE. UNITS ARE SPECIFIED BY KU. IF KR IS
                                                                               37
C
         SPECIFIED AS 1. P IS CHECKED FOR OUT OF SATURATION
                                                                               38
C
                                                                               39
      ENTRY PCHECK (KU, KR.P)
                                                                               40
      CHECK=P/PCONV(KU)
                                                                               41
      CH1= PCH1
                                                                               42
      CH2= PCH2
                                                                               43
      CH3= PCH3
                                                                               44
      KODE=0
                                                                               45
      DC 2 J=1.9
                                                                               46
    2 FMT(J)=FM2(J)
                                                                               47
      GO TO 10
                                                                               48
C
                                                                               49
          CONVERT DENSITY TO GICC AND CHECK
C
                                                                               50
          FOR CUT OF RANGE. UNITS ARE SPECIFIED BY KU.
C
                                                                               51
C
                                                                               52
       ENTRY CCHECK(KU.D)
                                                                               53
       CHECK =D/DCGNV(KU)
                                                                               54
       CH1=DCH1
                                                                               55
       CH3=DCH2
                                                                               56
       KDCE=0
                                                                               57
       DO 3 J=1.9
                                                                               58
     3 FMT(J)=FM3(J)
                                                                               59
       GG TO 20
                                                                               60
    10 IF(KR.EG.1) GO TO 30
```

20 IF (CHECK-LT-CH1) GO TO 40	41
IFICHECK.GT.CH3) GO TO 40	61 62
25 IF (KOCE-EO-1) CHECK=T/TCONV(KU)	63
RETURN	64
30 IF(CHECK-LT-CH1) GO TO 40	65
IF(CHECK.LE.CH2) GO TO 25	66
40 WRITE(6,FMT) CHECK.ROUT(IRCUT) GO TO 25	67
ENC	68
	69
SIBFIC SUB1	
SUBROUTINE CHUST(D)	•
C	2
CUMMUN /CENSTS/ TAUC.RHOB.RHOB.TAUA.F .R	3
COMMON /QAUX / RBDIF(8), RADIF(8), ER, ED, TADIF(7)	4
CGMMON /COF/ A(10.7)	5
COMMON/OS1/SUMI(7)	6
RADIF (1)= 1.0 RADIF (2) = D- RHOA	7
RBDIF (1) = 1.0	8
RBCIF (2) = D- RHOB	9
00 1 I= 3.8	10
RBCIF (1) = RBDIF (1-1) + RBDIF(2)	11
1 RADIF (I) = RADIF (I-1) *RADIF(2)	12
ED = E*D	13
ER= 1.0/ EXP(ED)	14
SUMI(1)=0.0	15
DO 4 [=1.8	16
4 SUMI(1)=SUMI(1)+A(1,1)+RADIF(1)	17
SUPI(1)=SUNI(1)+ER*(A(9.1)+A(10.1)+D)	18 19
DC 6 J=2.7	20
SUMI(J)=0.0	21
00 5 [=1.8	22
SUMI(J)=SUMI(J)+A([,J)+RBDIF(I)	23
(D*(L,0))+R*(A(9,J)+A(10,J)*D) (D*(J)=SUMI(J)+R+(A(9,J)+A(10,J)+D)	24
RETURN	25
ENTRY OPUST2(TAU)	26
TACIF (1) = 0.0	27
TACIF (2) = 1.0	28
TADIF (3) = TAL-TAUA	29
DO 2 [= 4.7	30
2 TADEF (1)= TADEF(1-1)* TADEF(3)	31
RETURN	32
END	33

SIBFT	C SUB2 Function gcalc(TAU)	1
c		2
	THE FUNCTION O(RHO.TAU)	3 4 5
C	COMMON/CHECKS/DCH1.DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.	6
	1HSCH1.HSCH2 COMMON /QAUX/ RBDIF(8), RAD[F(8),ER,ED, TAD[F(7)	7 8
	COMMON /COF / A(10.7)	9
	CCMMON/GS1/SUMI(7)	10
	TSUM = 0.0	11
	00 4 J=2.7	12
4	TSUM=TSUM+TADIF(J) +SUMI(J)	13
	QCALC=SUMI(1)+(TAU-TCH2)+TSUM	14
	RETURN	15 16
	ENC	
\$ [BF]	TC SUB3 FUNCTION OOTA(TAU)	1 2
C		3
C	FARTIAL DER OF O PO/PRHO	4
	COMMON /QAUX/ RBD [F(8),RAD [F(8),ER,ED,TAD [F(7)	5 6
	COMMON /COF/ A(10.7)	7
	COMMON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R COMMON/XMIÑUS/XM1(7)	8
	COMMON/OS2/SUMI(7)	9
	EQUIVALENCE (SUMI(1).SUM)	10
	1 TSUM=0.0	11
	00 2 J=2,7	12
	2 TSUM=TSUM+TAD[F(J)+SUM[(J)	13
	QDTA=SUM+(TAU-TAUC)+TSUM	14
	RETURN	15
	ENTRY OCT(C, TAU)	16
	SUM=0.0	17
_	DC 10 I=2.8	18
1	0 SUM=SUM+XM1([-1)*A([.1)*RADIF([-1)	19
	SUM=SUM+ER+(A(10.1)-E+(A(9.1)+A(10.1)+D))	20
	DC 15 J=2.7	21
	0.0=(L)1MUZ	22 23
•	DC 12 I=2.8 2 SUMI(J)=SUMI(J)+XMI(I-1)*A(I,J)*RBDIF(I-1)	23 24
, L	SUMI(J)=SUMI(J)+KMI(I-I)+A(I,J)+KDDIP(I-I) $SUMI(J)=SUMI(J)+ER+(A(10,J)-E+(A(9,J)+A(10,J)+D))$	25
	5 CCATINUE	26
	GO TO 1	27
	END	28
	78 1 7 WF	

r		
C PAR	TIAL DER OF O PO/PTAU	
CU	MMON /QAUX/RBDIF(A).RADIF(A).ER ED TAGETE.	
	TON JULEY MINUS	
CO	MMON /CCNSTS/TAUC.RHOA.RHOB.TAUA.E.R	(
CU		7
CB	MMON/XMINUS/XM1(7)	6
	UM1 = 0.0	9
	UM2 = 0.0	10
UG	18 J=3,7	11
10 TC	MI=TSUMI+XMI(J-2)*TADIF(J-1)*SUMI(J)	12
10 13	JM2=TSUM2+TADIF(J)*SUMI(J) JM2=TSUM2+SUMI(2)	13
OT	D=T SUM2+(TAU-TAUC)+T SUM1	14 15
B.F.	TURN	16
EN	· =· ·•	17
	•	18
FUN	CTION 02120(TAU)	1
FUA	CTION 0212D(TAU)	2
FUN 	CTION 02120(TAU)	2
FUN 	CTION 0212D(TAU) AL DER OF 0 P20/PTAU2 MON /QAUX/ RBD[F(8).RAD]F(8).EP.ED.TAD]E(7)	2 3 4
FUN PARTI COM COM	CTION 0212D(TAU) AL DER OF Q P2O/PTAU2 MON /QAUX/ RBDIF(8) RADIF(8) ER, ED, TADIF(7) MON /COF / A(10.7)	2 3 4 5
FUN 	CTION 0212D(TAU) AL DER OF 0 P2O/PTAU2 MON /QAUX/ RBDIF(8) RADIF(8) ER ED TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC RHOAD RHOW TAWARE R	2 3 4 5 6
FUN PARTI COM COM CCM COM	CTION 0212D(TAU) AL DER OF 0 P2O/PTAU2 MON /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/QS1/SUMI(7)	2 3 4 5
FUN — PARTI COM COM COM COM COM	CTION 0212D(TAU) AL DER OF 0 P2O/PTAU2 MON /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/OS1/SUMI(7) MON/XMINUS/XMI(7)	2 3 4 5 6 7
FUN — PARTI COM COM COM COM COM TSU	CTION Q212D(TAU) AL DER OF Q P2O/PTAU2 MON /QAUX/ RBOIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/QS1/SUMI(7) MON/XMINUS/XH1(7) M1 = 0.0	2 3 4 5 6 7 8
FUN — PARTI COM COM COM COM TSUI TSUI	CTION 0212D(TAU) AL DER OF 0 P2O/PTAU2 MON /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/OS1/SUMI(7) MON/XMINUS/XMI(7)	2 3 4 5 6 7 8 9
FUN — PARTI COM COM COM COM TSU TSU	CTION Q2T2D(TAU) AL DER OF Q P2O/PTAU2 MON /QAUX/ RBOIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/QS1/SUMI(7) MON/XMINUS/XH1(7) M1 = 0.0 M2 = 0.0 M2 = 0.0	2 3 4 5 6 7 8 9
FUN — PARTI COM COM COM COM TSU TSU TSU	CTION 0212D(TAU) AL DER OF 0 P20/PTAU2 MON /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R MON/OS1/SUMI(7) MON/XMINUS/XH1(7) M1 = 0.0 M2 = 0.0 M2 = 0.0 M3.7 M1=TSUM1+XM1(J-2)*TADIF(J-1)*SUMI(J) MJ.EG.3) GO TO 2	2 3 4 5 6 7 8 9 10
FUN — PARTI COM COM COM COM TSU TSU IF (CTION 0212D(TAU) AL DER OF 0 P20/PTAU2 MON /QAUX/ RBDIF(8) RADIF(8) ER ED TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC RHOA RHOB TAUA E, R MON/OS1/SUMI(7) MON/MINUS/XHI(7) MI = 0.0 M2 = 0.0 M2 = 0.0 M3 = 3.7 M1=TSUM1+XMI(J-2) * TADIF(J-1) * SUMI(J) M3 = G-3) GO TO 2 M2=TSUM2+XMI(J-2) * XMI(J-3) * TADIF(J-3) * COUNTAIN	2 3 4 5 6 7 8 9 10 11 12 13
FUN PARTI COM COM COM COM TSUI TSUI IF (TSUI 2 COM	CTION Q212D(TAU) AL DER OF Q P2O/PTAU2 MON /QAUX/ RBOIF(8) RADIF(8) ER ED TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC RHOA RHOB TAUA E, R MON/QS1/SUMI(7) MON/XMINUS/XH1(7) M1 = 0.0 M2 = 0.0 M2 = 0.0 M3 = 3.7 M1=TSUM1+XM1(J-2) * TADIF(J-1) * SUMI(J) M3 = C-3) GO TO 2 M2=TSUM2+XM1(J-2) * XM1(J-3) * TADIF(J-2) * SUMI(J) INUE	2 3 4 5 6 7 8 9 10 11 12 13 14
PARTI COM COM COM COM TSU TSU IF (TSU IF COM	CTION Q212D(TAU) AL DER OF Q P2Q/PTAU2 MON /QAUX/ RBOIF(8) RADIF(8) ER ED TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC RHOA RHOB TAUA E, R MON/QS1/SUMI(7) MON/XMINUS/XMI(7) M1 = 0.0 M2 = 0.0 M2 = 0.0 M2 = 0.0 M3 = 3.7 M41=TSUM1+XMI(J-2) * TADIF(J-1) * SUMI(J) M3 = C-3) GO TO 2 M3 = TSUM2+XMI(J-2) * XMI(J-3) * TADIF(J-2) * SUMI(J) MON/XMINUS/XMI(J-2) * XMI(J-3) * TADIF(J-2) * SUMI(J) MARCH 1.1972	2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
FUN PARTI COM COM COM COM TSUI TSUI IF (TSUI 2 COM	CTION Q212D(TAU) AL DER OF Q P2Q/PTAU2 MON /QAUX/ RBOIF(8) RADIF(8) ER ED TADIF(7) MON /COF / A(10.7) MON /CONSTS/ TAUC RHOA RHOB TAUA E, R MON/QS1/SUMI(7) MON/XMINUS/XMI(7) M1 = 0.0 M2 = 0.0 M2 = 0.0 M2 = 0.0 M3 = 3.7 M41=TSUM1+XMI(J-2) * TADIF(J-1) * SUMI(J) M3 = C-3) GO TO 2 M3 = TSUM2+XMI(J-2) * XMI(J-3) * TADIF(J-2) * SUMI(J) MON/XMINUS/XMI(J-2) * XMI(J-3) * TADIF(J-2) * SUMI(J) MARCH 1.1972	2 3 4 5 6 7 8 9 10 11 12 13 14

BFTC SUB6 Function	N Q2DTA(TAU)
PARTIAL	DER OF Q P2Q/PRHO-PTAU /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7)
COMMON	/COF/ A(10+7) /CONSTS/ TAUC+RHOA+RHCB+TAUA+E +R
	QS3/SUM(6)
	ussisum(d) xminus/xml(7)
1 TSUM1=0	
•	
TSUM2=0	
00 10 J	-3.* SUM1+XM1(J-2)+TAD1F(J-1)+SUM(J-1)
	SUM2+TADIF(J)+SUM(J-1)
	SUMS+SUM(1)
	SUM1+(TAU-TAUC)
	SUM1+TSUM2
RETURN	30/1/100/14
	201(D. TAU)
00 20 1	
SUP(J-1	
DO 15 I	
15 SUM(J-1)=SUN(J-1)+XM1(I-1)A(I,J)*RDIF(I-1)
SUM(J-1)=SUM(J-1)+ER*(A(10,J)-E*(A(9,J)+A(10,J)*D))
20 CONTINU	
GC TO 1	
END	
	IN Q2D2TA(TAU)
FUNCTIO	ON G2D2TA(TAU)
FUNCTIO	
FUNCTIO	DER OF Q P20/PRHO2
FUNCTIO	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7)
PARTIAL COMMON COMMON	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7)
FUNCTIO	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R
FUNCTION PARTIAL COMMON COMMON COMMON COMMON	DER OF Q P2O/PRHO2 /OAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /OS4/SUMI(7)
FUNCTION PARTIAL COMMON COMMON COMMON COMMON COMMON	DER OF Q P2O/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7)
FUNCTION PARTIAL COMMON COMMON COMMON COMMON COMMON TSUM=0	DER OF Q P2O/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7)
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J	DER OF Q P2O/PRHO2 /OAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) .0 =2.7
FUNCTION PARTIAL COMMON COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XH1(7) O = 2.7 SUM+TADIF(J)*SUMI(J)
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J 5 TSUM=T O2C2TA	DER OF Q P2O/PRHO2 /OAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) .0 =2.7
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN	DER OF Q P2Q/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) *O =2.7 SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY	DER OF Q P2Q/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) **O =2.7 SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUM [1]	DER OF Q P2Q/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) =2.7 SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) =0.0
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUMILL DO 3 L	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D202T(D.TAU) 3-0.0 =3.8
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J 5 TSUM=T O2C2TA RETURN ENTRY SUM[[1] DO 3 []	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D202T(D.TAU) =
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUMI(1 DO 3 I 3 SUMI(1 SUMI(1)	DER OF Q P20/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) =2.7 SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) =0.0 =3.8)=SUMI(1)+XMI(I-1)*XMI(I-2)*A(1.1)*RADIF([-2))=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1))
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUMI(1 DO 3 I SUMI(1 SUMI(1 DC 10	DER OF O P2O/PRHO2 /OAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /OS4/SUMI(7) /XMINUS/XMI(7) =0.0 =2.7 SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) =0.0 =3.8)=SUMI(1)+XMI(I-1)*XMI(I-2)*A(I.1)*RADIF([-2))=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1)) J=2.7
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUMI(1 DO 3 I SUMI(1 DO 10 SUMI(1)	DER OF Q P2Q/PRHO2 /QAUX/ RBDIF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XM1(7) =SUM+TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) = =
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J 5 TSUM=T O2G2TA RETURN ENTRY SUMI(1) DO 3 I SUMI(1) DO 10 SUMI(1) DO 8 I	DER OF Q P2Q/PRHO2 /QAUX/ R8D IF(8).RAD IF(8).ER.ED.TAD IF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /OS4/SUMI(7) /XMINUS/XH1(7) -0 =2.7 SUM+TAD IF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) =
FUNCTION PARTIAL COMMON COMMON COMMON COMMON TSUM=0 DO 5 J 5 TSUM=T O2C2TA RETURN ENTRY SUMI(1 DO 3 I SUMI(1 DC 10 SUMI(1 DC 10 SUMI(1 DO 8 I 8 SUMI(1)	DER OF Q P2Q/PRHO2 /QAUX/ R8D IF(8).RADIF(8).ER.ED.TADIF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /OS4/SUMI(7) /XMINUS/XMI(7) -O =2.7 SUM-TADIF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) D=0.0 =3.8 D=SUMI(1)+XMI(I-1)*XMI(I-2)*A(1.1)*RADIF([-2) D=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1)) J=2.7 J=2.7 J=3.8 D=SUMI(J)+XMI(I-1)*XMI(I-2)*A(I.J)*R8DIF(I-2)
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T 02C2TA RETURN ENTRY SUMI(1 DO 3 I 3 SUMI(1 DO 10 SUMI(1 DO 8 I 8 SUMI(J SUMI(J SUMI(J	DER OF Q P20/PRHO2 /QAUX/ R8D IF(8).RAD IF(8).ER.ED.TAD IF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHO8. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) -O =2.7 SUM+TAD IF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) =3.8 D=SUMI(1)+XMI(I-1)*XMI(I-2)*A(I.1)*RAD IF(I-2) D=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1)) J=2.7 J=0.0 =3.8 D=SUMI(J)+XMI(I-1)*XMI(I-2)*A(I.J)*RBD IF(I-2) D=SUMI(J)+ER*(-E*A(10.J)*(2.0-ED)+E*E*A(9.J))
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T Q2C2TA RETURN ENTRY SUMI(1 DO 3 I SUMI(1 DO 3 I SUMI(1 DO 10 SUMI(1 DO 8 I SUMI(1 DO 8 I SUMI(1 CONTIN	DER OF 0 P20/PRHO2 /QAUX/ RBD IF(8).RAD IF(8).ER.ED.TAD IF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) -O=2.7 SUM-TAD IF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) ==0.0 ==3.8 D=SUMI(1)+XMI(I-1)*XMI(I-2)*A(I.1)*RAD IF([-2) D=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1)) J=2.7 D=SUMI(J)+XMI(I-1)*XMI(I-2)*A(I.J)*RBD IF(I-2) D=SUMI(J)+ER*(-E*A(10.J)*(2.0-ED)+E*E*A(9.J)) UE
FUNCTION PARTIAL COMMON COMMON COMMON COMMON 1 TSUM=0 DO 5 J 5 TSUM=T 02C2TA RETURN ENTRY SUMI(1 DO 3 I 3 SUMI(1 DO 10 SUMI(1 DO 8 I 8 SUMI(J SUMI(J SUMI(J	DER OF 0 P20/PRHO2 /QAUX/ RBD IF(8).RAD IF(8).ER.ED.TAD IF(7) /COF/ A(10.7) /CONSTS/ TAUC. RHOA. RHOB. TAUA. E. R /QS4/SUMI(7) /XMINUS/XMI(7) -O=2.7 SUM-TAD IF(J)*SUMI(J) =SUMI(1)+(TAU-TAUC)*TSUM D2D2T(D.TAU) ==0.0 ==3.8 D=SUMI(1)+XMI(I-1)*XMI(I-2)*A(I.1)*RAD IF([-2) D=SUMI(1)+ER*(-E*A(10.1)*(2.0-ED)+E*E*A(9.1)) J=2.7 D=SUMI(J)+XMI(I-1)*XMI(I-2)*A(I.J)*RBD IF(I-2) D=SUMI(J)+ER*(-E*A(10.J)*(2.0-ED)+E*E*A(9.J)) UE

\$18FTC SUB8

SUBROUTINE PSSS(PSS)	
C	2
C	3
C COMPUTE SATURATION PRESSURE PSSS IN BARS AS A FUNCTION OF T IN DEGRE	ES 4
C C AND RETURN ANSHER IN PSS IN MN/M**2	5
COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7	6
C THE T IN THE COMMON BENDIT IS REALLY TAU	<i>'</i>
COMMON/TPARAM/T	8
DIMENSION CTIPS(6)	9
	10
DATA CTIPS / .31602383E-03 , 1.00044775, -0.46487771E-05,	11
1 0.69431852E-08, 0.15621197E-12 , 1.00043357 /	12
TSC = 1000./T -273.15	13
CCONVERT TSCITHERMODYNAMIC CELSIUS TO INT.PRACTICAL SCALE (C) WHIC	CH 14
CIS USED IN SATURATION EQUATION	15
IF (TSC .GE. 9.996) GO TO 9	16
TS = CTIPS(6) + TSC	17
GO TO 10	18
9 TS = (((CTIPS(5)*TSC+CTIPS(4))*TSC + CTIPS(3))*TSC +CTIPS(2))	19
1 *TSC + CTIPS(1)	20
10 TS=TS+273.15	21
PSS=10.**((((CPS7*TS+CPS6)*TS+CPS5)*TS+CPS4)*TS+CPS3)*TS+CPS2/TS	5+ 22
1CPS1)	23
PSS=PSS/10.0	24
RETURN	
END	25
	26

```
1
     FUNCTION TSS(PS)
       C
C
      COMPUTE SATURATION TEMPERATURE IN DEG C AS A FUNCTION OF PRESSURE
C
       IN BARS AND RETURN ANSWER TSS AS TAU IN KELVIN++-1
C
C
                                                                           7
     COMMON/CHECKS/DCH1(1).DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.H
                                                                           8
    1SCH1.HSCH2
                                                                           9
     COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
                                                                          10
     COMMON/BEND9/A1, A2, A3, A4, A5
                                                                          11
     DIMENSION CTT(6)
     DATA CTT /-.30733645E-03, 0.99955209,0.46490458E-05,-.69336443E-08
                                                                          12
    1,-0.18086305E-12 , .99956709 /
                                                                          13
                                                                          14
     EXTERNAL TSSF.DTSSF
                                                                          15
     PS1=PS+10.0
                                                                          16
     A1=CPS1-ALGG10(PS1)
     A2=5.+CPS7
                                                                          17
     A3=4. +CPS6
                                                                          18
     A4=3. +CPS5
                                                                          19
                                                                          20
     A5=2. +CPS4
                                                                          21
     TESTM =(1000./TCH2 -20.0 )
                                                                          22
     TSS=SOLVE(TESTM, TSSF, CTSSF)
     TSS=TS$-273.15
                                                                          23
C---CONVERT THE CALCULATED SATURATION TEMP. FROM INT. PRACTCAL SCALE
                                                                          24
                                                                          25
C----(C) TO THERMODYNAMIC CELSIUS SCALE
                                                                          26
     TSIP=TSS
     IF (TSS .GT. 10.) GO TO 9
                                                                          27
     TSS = CTT(6)* TSS
                                                                          28
                                                                          29
     GO TO 10
    9 TSS = (((CTT(5)*TSS + CTT(4))*TSS + CTT(3))*TSS + CTT(2))*TSS +
                                                                          30
                                                                          31
              CTT(1)
    1
                                                                          32
   10 \text{ TSS} = 1000./(TSS+273.15)
                                                                          33
     RETURN
                                                                          34
      END
SIBFTC SUB10
      FUNCTION ISSF(ISS)
          C
C
C
        FUNCTION USED TO SOLVE FOR SATURATION TEMPERATURE TSS
                                                                           5
        GIVEN PRESSURE
                                                                           6
C
      COMMON/COSAT/ CPS1 .CPS2.CPS3.CPS4.CPS5.CPS6.CPS7
                                                                           7
      COMMON/8END9/A1.A2.A3.A4.A5
                                                                           8
                                                                           9
      TSSF=((((CPS7*TSS+CPS6)*TSS+CPS5)*TSS+CPS4)*TSS+CPS3)*TSS+CPS2/
                                                                          10
     ITSS+A1
                                                                          11
      RETURN
                                                                          12
      ENTRY
              DISSF(ISS)
                                                                          13
C
         DERIVATIVE OF FUNCTION USED TO SULVE FOR SATURATION
                                                                          14
                                                                          15
C
         TEMPERATURE ISS GIVEN PRESSURE
                                                                          16
       TSSF=(((A2+TSS+A3)+TSS+A4)+TSS+A5)+TSS+CPS3-CPS2/(TSS+TSS)
                                                                           17
                                                                           18
      RETURN
                                                                           19
```

END

```
SIBFIC PRESI
       SUBROUTINE PRESS(KU.T.D.P.KR)
 C
           VERSION MARCH 1.1972-----
 C
          COMPUTE PRESSURE P GIVEN TEMPERATURE T AND CENSITY D.
 C
          UNITS ARE SPECIFIED BY KU. IF KR IS RETURNED OR
 C
 C
          SPECIFIED AS 1. P IS COMPUTED AT SATURATION AS A
 C
          FUNCTION OF T ONLY.
       COMPON /CONV3/PCONV(5)
                                                                                 8
                                                                                 9
       COMMEN/TPARAM/TS
       COMMON /CCNSTS/ TAUC+RHOA+RHOB+TAUA+E +R
                                                                                10
       COMMON/CHECKS/DCH1.DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.
                                                                                11
      1HSCH1.FSCH2
                                                                                12
       COMMON/IERROR/IROUT
                                                                                13
       IROUT=2
                                                                                14
       TS=TCHECK(KU.KR.T)
                                                                                15
 C
                                                                                16
 C
                                                                                17
          DETERMINE REGION
 C
                                                                                18
       [F (KR-1) 10.70.10
                                                                                19
    10 DS=DCHECK(KU.D)
                                                                               20
       IF ( KR -GT- 1) GO TO 80
                                                                               21
       IF (TS-TCH2) 50.50.20
                                                                               22
   20 CALL DENS(1.TS.ZE.ZE.DSL.DSV.1)
                                                                               23
       IF (DS-DSL) 30.60.40
                                                                               24
   30 IF (DS-DSV) 50.60.60
                                                                               25
   40 KR=2
                                                                               26
      GO TO 80
                                                                               27
   50 KR=3
                                                                               28
      60 TO 80
                                                                               29
                                                                               30
C
         REGION 1
                                                                               31
C
                                                                               32
   60 KR=1
                                                                               33
   70 CALL PSSS(PS)
                                                                               34
      GO TO 90
                                                                               35
C
                                                                               36
C
         REGIONS 2 AND 3
                                                                               37
(
                                                                               38
   BC CALL OMUSTICS)
                                                                               39
     CALL OMUSTZ(TS)
                                                                               40
     PS=1000.*R*DS/TS*(1.+DS*(QCALC(TS)+DS*QDT(DS,TS)))
                                                                               41
   90 P=PS+PCONV(KU)
                                                                              42
      RETURN
                                                                              43
      ENC
                                                                              44
                                                                              45
```

```
SIBFIC CENSI
      SUBROUTINE DENS(KU.T.P.D.DL.DV.KR)
       C
(
        COMPUTE DENSITY D GIVEN TEMPERATURE T AND PRESSURE P.
C
         UNITS ARE SPECIFIED BY KU. IF KR IS RETURNED OR
C
         SPECIFIED AS 1. THE SATURATED LIQUID AND VAPOR DENSITIES.
C
                                                                               7
         DL AND DV RESPECTIVELY. ARE COMPUTED AS A FUNCTION
C
                                                                               R
         OF T OR P. THE OTHER VALUE MUST BE INPUT AS 0.0 .
C
                                                                               9
C
                                                                              10
      COMMON /CHECKI/NI
                                                                              11
      COMMON /CONVI/DCONV(5)
                                                                              12
      COMMON/CONV2/TCGNV(5)
                                                                              13
      COMMON/CONV3 /PCONV(5)
                                                                              14
      COMMON/IERROR/IROUT
                                                                              15
      COMMON /CRIT/ RHOCRT.PCRT.TCRT
                                                                              16
      COMMON/ PSICON/ SIC1.SIC2.SIC3.SIC4.SIC5
                                                                              17
      COMMON /CONSTS/ TAUC.RHOA.KHOB.TAUA.E .R
      CGMMON/CHECKS/DCH1.DCH2.PCH1.PCH2.PCH3.TCH1.TCH2.TCH3.DST.TST.
                                                                              18
                                                                              19
     1HSCH1. HSCH2
                                                                              20
      CGMMON/TPARAM/TS
                                                                              21
      COMMON /PRHOT/PS.DS.TT
                                                                              22
      EXTERNAL DSF.DDSF
                                                                              23
      [ROUT=1
                                                                              24
      IF (KR.EQ.1) GO TO 70
                                                                              25
      TS=TCHECK(KU,KR,T)
                                                                              26
      TT = TS
                                                                              27
      CALL OMUSTZ(TS)
                                                                              28
      GO TO 5
                                                                              29
   70 IF (T.61.0.0) 60 TO 75
                                                                              30
      PS=PCHECK(KU-KR-P)
                                                                              31
      TS=TSS(PS)
                                                                              32
       TT = TS
                                                                              33
      IF (T.LE.O.) T=TS *TCONV(KL)
                                                                              34
      CALL OMUST 2(TS)
                                                                              35
      GO TO 5
                                                                              36
   75 TS = TCHECK (KU-KR-T)
                                                                              37
      TT = TS
                                                                              38
      CALL QMUST2(TS)
                                                                              39
      CALL PSSS(PS)
                                                                              40
      IF (P.LE.O.) P=PS *PCONV(KU)
                                                                               41
                                                                               42
         DETERMINE REGION
C
                                                                               43
                                                                               44
     5 IF (KR-1) 10,80,10
                                                                               45
    10 PS=PCHECK(KU,KR.P)
                                                                               46
       IF (PS-PCH2)110.110.100
                                                                               47
   100 IF (TS-TCH2)130,130,120
                                                                               48
   120 KR=2
                                                                               49
      EST1 = 1.0455
                                                                               50
       EST2 = RHOCRT
                                                                               51
       TEST = 1000./TS - 273.15
                                                                               52
       IF ( TEST .GT. 100.) EST1 = 1.0107054
                                                                               53
       IF ( TEST .GT. 180.0) GO TO 121
                                                                               54
       IF (TEST-LT-40.) TEST=40.
       EST2=(1EST*(TEST*(TEST*(TEST*.12476711E-09-.52277795E-07)
                                                                               55
                                                                               56
      1 +.54790571E-051-.69617325E-031+1.0220277 )
                                                                               57
   121 CALL RCGT (EST1.EST2.0..DSF.DS)
                                                                               58
       GC TO 150
                                                                               59
   130 KR=3
                                                                               60
       EST=RHOCRT+3.
```

	CALL RODT(EST.DCH1.0CSF.DS)	
	GO TO 150	61
11	0 IF (TS-TCH2) 50.50.20	62
2	O CALL PSSS(PSS)	63
	IF (ABS((PSS-PS)/PSS)-1-E-4) 6(,30,30	64
3	0 IF (PS-PSS) 50.60.40	65
4	0 KA=2	66
	1 DS=.71454566	67
	IF (TS .GT. 1.7447439) DS = .822368	68
	IF(TS .GT. 1.9487479) DS = .8474576	69
	IF (TS .GT. 2.0277805) DS = .907441	70
	IF (TS .GT. 2.3086690) DS=.961538	71
	IF (TS .GT. 2.6798874) DS = 1.001001	72
	IF (KR .EQ. 1) GO TO 81	73
,	GO TO 90	74
5(0 KR=3	75
	DS = PS+TS/(1000.+R)	76
	60 TO 90	77
C		78
C	REGICN 1	79
C		80
60) KR=1	81
80	CONTINUE	82
	GO TO 41	83
81	CONTINUE	84
	DSL=SOLVE(DS.DSF.ODSF)	85
	DS = PS*TS/(1000.*R)	86
	IF (TCH2/TS-GT985)DS=-65*RHOCRT	87
	IF (TCH2/TS-GT995) DS=-75*RHDCRT	88
	IF (TCH2/TS-GT999) DS=-85*RHCCRT	89
	IF (TCH2/TS-GT9995) DS=.90*RHOCRT	90
	DSV=SOLVE(DS.DSF.DDSF)	91
	DL=DSL+CCONV(KU)	92
	DV=DSV+DCONV(KU)	93
	RETURN	94
C		95
C	REGIONS 2 AND 3	96
C	The second of th	97
90	DS=SOLVE(DS.DSF.ODSF)	98
150	D=DS+DCGNV(KU)	99
	RETURN	100
	ENC	101
		102

\$18F	TC DSF1	1 2
C C	FUNCTION USED TO SOLVE FOR DENSITY D GIVEN TEMPERATURE	3
C	AND PRESSURE	5
(COMMON /CONSTS/ TAUC.RHOA.RHOB.TAUA.E .R COMMON /PRHCT/ PS.DS.TS CALL QMUST(D) PSTATE=1000.*R*D /TS*(1.+D *(QCALC.(TS)+D *QDT(D ,TS))) DSF=PSTATE-PS RETURN	6 7 8 9 10 11
C	ENTRY DESFIC } CALL GMUST(D) DDSF=1000.*R/TS*(1.+D*(2.0*QCALC(TS)+4.0*D*QDT(D.TS)+D*D*Q2D2T(D.TS))) DSF=DDSF RETURN	12 13 14 15 16 17

SIBFTC TEMP1

```
SUBROUTINE TEMP(KU,P,D,T,KR)
 C
         C
 C
    COMPUTE TAU=1000./TEMPERATURE IN USERS UNITS GIVEN PRESSURE AND DEN-
 C
    SITY. IF KR IS SPECIFIED AS 1 TAU WILL BE A FUNCTION OF PRESSURE ONLY
                                                                                5
 C
                                                                                6
 C
 C
                                                                                7
       COPPON /CONV2/TCONV(5)
                                                                                8
       COMMON/CHECKS/OCH1, DCH2, PCH1, PCH2, PCH3, TCH1, TCH2, TCH3, DST, TST,
                                                                                9
                                                                               10
      1HSCH1, HSCH2
                                                                               11
       COMMON/IERROR/IROUT
       COMMON /PRHOTT/ PS,DS,TS
                                                                               12
                                                                               13
       EXTERNAL TSF, DTSF
                                                                               14
       IROUT=3
                                                                               15
       PS=PCHECK(KU,KR,P)
C
                                                                               16
C
                                                                               17
          DETERMINE REGION
                                                                               18
       IF (KR-1) 10,70,10
                                                                               19
    10 DS=DCHECK(KU,D)
                                                                               20
                                                                               21
       IF (PS-PCH2) 20,20,50
                                                                               22
    20 TS=TSS(PS)
      CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
                                                                              23
                                                                              24
      IF (DS-DSL) 30,60,40
   30 IF (DS-DSV) 50,60,60
                                                                              25
                                                                              26
   40 KR=2
                                                                              27
      TS = TS+.01
                                                                              28
      GO TO 80
   50 KR=3
                                                                              29
      TS=1.2
                                                                              30
                                                                              31
      GO TO 80
                                                                              32
C
C
                                                                              33
         REGION 1
C
                                                                              34
                                                                              35
   60 KR=1
                                                                              36
      GO TO 110
   70 TS=TSS(PS)
                                                                              37
                                                                              38
      GO TO 110
                                                                              39
C
                                                                              40
C
         REGIONS 2 AND 3
C
                                                                              41
                                                                              42
   80 CALL QMUST(DS)
                                                                              43
      CALL QDT(DS,TS)
                                                                              44
      CALL Q2DT(DS,TS)
                                                                              45
      TS=SOLVE(TS,TSF,DTSF)
C
                                                                              46
                                                                              47
C
         VERIFY REGION
                                                                             48
                                                                              49
     IF (PS-PCH2)110,110,90
                                                                             50
  90 IF (TS-TCH2) 110,100,100
                                                                              51
 100 KR=2
                                                                             52
 110 T=TS+TCONV(KU)
                                                                             53
     RETURN
                                                                             54
     END
```

55

2

```
SIBFTC TSF1
     FUNCTION TSF(TS)
                 C
                                                                          3
        FUNCTION USED TO SOLVE FOR TEMPERATURE TS GIVEN PRESSURE
ſ
C
        AND DENSITY
C
•
                                                                           7
     COMMON /PRHOTT/ PS.D .T
                                                                           8
     COMMON /CGNSTS/ TAUC.RHOA.RHCB.TAUA.E .R
                                                                           9
     CALL OMUSTZ(TS)
                                                                          10
     PSTATE=1000.*R*D /TS*(1.+D *(QCALC(TS)+D *QDTA(TS)))
                                                                          11
     TSF=PSTATE-PS
                                                                          12
      RETURN
                                                                          13
C
                                                                          14
      ENTRY DISFL TS
                                                                          15
     CALL OMUSTZ(TS )
     DTSF=R+D+((1.0+D+D+QDTA (TS )+D+QCALC(TS ))-TS +D+(D+Q2DTA(TS )
                                                                          16
                                                                          17
     1+0TD(TS )))
                                                                          18
      DTSF=DTSF+(-1000./(TS *TS ))
                                                                          19
      TSF=OTSF
                                                                          20
      RETURN
                                                                          21
      END
 SIBFTC ENTH1
      SUBROUTINE ENTH(KU,TT,D,H)
        3
 C
       THIS ROUTINE COMPUTES ENTHALPY GIVEN THE TEMPERATURE PARAMETER TT
 C
 C
       AND THE DENSITY D. I/O UNITS ARE SPECIFIED BY KU.
                                                                            5
     IF SATURATION VALUES ARE NEEDED, THIS ROUTINE MUST BE CALLED TWICE
 C
                                                                            7
 C
       WITH DL AND DV INPUT AS D.
 C
                                                                            8
               ENTHALPY IS RETURNED IN H.
 C
                                                                            9
                                                                           10
 C
       COMMON/IERROR/IROUT
                                                                           11
       COMMON/CCNV6/HCONV(5)
                                                                           12
       COMMON/SICOF / PSI1.PSI2.PSI3.PSI4.PSI5
                                                                           13
       COMMON /CONSTS/ TAUC, RHOA, RHOB, TAUA, E, R
                                                                           14
       IROUT=4
                                                                           15
       TS=TCHECK (KU, KR, TT)
                                                                           16
       DS=DCHECK(KU,D)
                                                                           17
       CALL QMUST(DS)
                                                                           18
       CALL QMUST2(TS)
                                                                           19
       T=1000./TS
                                                                           20
        PSIQ= (PSI3+T+PSI2)+T+PSI1+(PSI4+PSI5+T)+ALOG(T)
       PSIT=2.*PSI3*T +PSI2+PSI4/T +PSI5*(1.+ALOG(T ))
                                                                           21
                                                                           22
       H1= PSIO-T*PSIT
       H2=1000.+R/TS+(1.+DS+(QCALC(TS)+TS+QTD(TS)+DS+QDT(DS,TS)))
                                                                           23
                                                                           24
       H=(H1+H2)+HCONV(KU)
                                                                            25
       RETURN
                                                                            26
```

END

SIBFTC ENTL

C	VERSION MARCH 1,1972	
C		
C	THIS ROUTINE COMPUTES ENTROPY GIVEN THE TEMPERATURE PARAMETER TT	
С	AND THE DENSITY D. I/O UNITS ARE SPECIFIED BY KU.	
С	IF SATURATION VALUES ARE NEEDED, THIS ROUTINE MUST BE CALLED THICE	
C	WITH DL AND DY INPUT AS D.	
Č	ENTROPY IS RETURNED IN S.	
Č	ENTROL IS RETURNED IN 3.	
•	COMMON/SICOF / PSI1, PSI2, PSI3, PSI4, PSI5	
	COMMON /CONSTS/ TAUC, RHOA, RHOB, TAUA, E , R	1
	COMMON/IERROR/IROUT	1
	COMMON/CONV4/SCONV(5)	1
	IROUT=5	1
	TS=TCHECK(KU,KR,TT)	1.
	DS=DCHECK(KU.D)	1:
	CALL QMUST(DS)	1
		1
	CALL QMUST2(TS)	1
	T=1000./TS	19
	PSIT=2.*PSI3+T +PSI2+PSI4/T +PSI5*(1.+ALOG(T))	20
	SSS=-R*(ALOG(DS)+DS*(QCALC(TS)-TS*QTD(TS)))-PSIT	2
	S=SSS+SCCNV(KU)	2
	RETURN	2
	END	2

SIBFTC TEMPP1

```
SUBROUTINE TEMPPH(KU,P,H,T,D,DL,DV,KR)
        2
C
                                                                               3
     COMMON /CONVI/DCONV(5)
                                                                               4
      COMMON /CONV2/TCONV(5)
                                                                               5
      COMMON/CCNV6/HCONV(5)
                                                                               6
      COMMON/PHCALL/PS, HS , SS
     COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
                                                                               7
                                                                               8
     1HSCH1, HSCH2
                                                                               9
      COMMON/IERROR/IROUT
                                                                              10
      EXTERNAL TSHF
                                                                              11
      PS=PCHECK(KU,KR,P)
                                                                              12
      IROUT=6
                                                                              13
      HS=P/HCGNV(KU)
                                                                              14
      IF (HS-HSCH1) 20,10,10
                                                                              15
   10 IF (HS-HSCH2) 40,40,20
                                                                              16
C
                                                                              17
         INPUT H - OUT OF RANGE TAG
                                                                              18
   20 WRITE(6,301) HS, HSCH1, HSCH2
  301 FORMAT (10HOINPUT H = +G14.6, 29HJ/G IS OUT OF RANGE OF HMIN=
                                                                              19
                                                                              20
     1 .F4.1, 10HAND HMAX = ,F7.1, 3HJ/G )
                                                                              21
                                                                              22
   40 IF (PS-PCH2! 140,140,130
                                                                              23
  130 TS1=TCH1
                                                                              24
      TS2=TCH3
                                                                              25
      GO TO 110
                                                                              26
  140 TS=0.0
                                                                              27
      CALL DENS(1,TS,PS,ZE,DL,CV,1)
                                                                              28
      IF (KR-1) 50,70,50
                                                                              29
   50 CALL ENTH(1,TS,DL,HSL)
                                                                              30
      CALL ENTH(1,TS,DV,HSV)
                                                                              31
      IF (HS-HSL) 90,70,60
                                                                              32
   60 IF (HS-HSV) 70,70,100
                                                                              33
C
                                                                              34
         REGION 1
C
                                                                              35
Č
                                                                              36
   70 KR=1
                                                                              37
   80 CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
                                                                              38
      DL=DSL+DCONV(KU)
                                                                              39
      DV=DSV+DCONV(KU)
                                                                              40
      GO TO 120
                                                                              41
C
                                                                              42
         REGION 2
C
                                                                              43
C
                                                                              44
   90 KR=2
                                                                               45
      TS1=TCH3
                                                                               46
      PS=PS*1.00011
                                                                               47
      TS2=1000./(1000./TS-1.E-5)
                                                                               48
      GO TO 110
                                                                               49
C
                                                                               50
         REGION 3
C
                                                                               51
                                                                               52
   100 KR=3
                                                                               53
       TS1=1000./(1000./TS+1.E-5)
                                                                               54
       PS= PS+.99988
                                                                               55
```

TS2=TCH1

C		
C	REGIONS 2 AND 3	56
Č	MEGICAS & AND 3	57
		58
110	CALL ROOTX(TS1,TS2,HS,TSHF,TS)	59
	CALL DENS(1,TS,PS,DS,ZE,ZE,KR)	60
	D=DS+DCCNV(KU)	
C		61
Č	VERIFY REGION	62
č	TEAT CEGIUM	63
L	15 100 00000 100 100 100	64
	IF (PS-PCH2) 120,120,150	65
150	1 1F (TS-TCH2) 170,170,160	
160) KR=2	66
	GO TO 120	67
170	KR=3	68
		69
120	T=TS+TCCNV(KU)	70
	RETURN	71
	END	
		72

SIBFTC STEMPS

```
SUBROUTINE TEMPPS (KU,P,S,T,D,DL,DV,KR )
        VERSION MARCH 1,1972-----
C
                                                                                3
      COMMON /CONVI/CCONV(5)
      COMMON/CENV4/ SCONV(5)
      CCPMON /CONV2/TCONV(5)
                                                                                6
      CCMMON/PHCALL/PS.HS .SS
      COMPON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
                                                                                7
                                                                                8
     1HSCH1, HSCH2
                                                                                9
      COMMON/IERROR/IROUT
                                                                               10
      EXTERNAL TPSF
                                                                               11
      IROUT=7
                                                                               12
      SMAX=13.26
                                                                               13
      PS=PCHECK(KU, KR, P)
                                                                               14
      SS = S/SCONV(KU)
                                                                               15
      IF (SS .LT. 0.0) GO TC 20
                                                                                16
      IF ( SS.LE.SMAX) GO TO 40
                                                                                17
C
                                                                                18
                    OUT OF RANGE TAG
       INPUT S
                                                                                19
   20 WRITE(6,301) SS, SMAX
  301 FORMAT (10HOINPUT S = ,G14.6, 47HJ/G-K IS OUT OF RANGE OF SMIN=0.
                                                                                20
                                                                                21
                   .F7.1,5HJ/G-K)
     10 AND SMAX=
                                                                                22
   40 IF (PS-PCH2) 140,140,130
                                                                                23
  130 TS1=TCH1
                                                                                24
      TS2=TCH3
                                                                                25
      GO TO 110
                                                                                26
  140 TS=0.0
                                                                                27
      CALL DENS(1,TS,PS,ZE,DL,DV,1)
                                                                                28
      IF (KR-1) 50,70,50
                                                                                29
   50 CALL ENT(1,TS,DL,SSL)
                                                                                30
      CALL ENT(1,TS,DV,SSV)
                                                                                31
      IF ( SS-SSL ) 90,70,60
                                                                                32
   60 IF ( SS-SSV) 70,70,100
                                                                                33
C
                                                                                34
          REGICN 1
C
                                                                                35
                                                                                36
   70 KR=1
                                                                                37
   80 CALL DENS(1,TS,ZE,ZE,CSL,DSV,1)
                                                                                38
      DL=DSL+DCONV(KU)
                                                                                39
      DV=DSV+DCONV(KU)
                                                                                40
      GC TO 120
                                                                                41
C
                                                                                42
          REGICN 2
 C
                                                                                43
C
                                                                                44
    90 KR=2
                                                                                45
       TS1=TCH3
                                                                                46
       PS=PS+1.00011
                                                                                47
       TS2=TS+1.00001
                                                                                48
       GO TO 110
                                                                                49
 C
                                                                                50
          REGICN 3
 C
                                                                                 51
                                                                                52
   100 KR=3
                                                                                53
       TS1=TS*.99999
                                                                                54
       PS= PS+.99988
                                                                                 55
       TS2=TCH1
```

C		56
C	REGICNS 2 AND 3	57
-	O CALL BOOTY / TS) TCO CC TACE TO .	58
	CALL DENS(1 TS DE DE TE TE ME)	59
	CALL DENS(1,TS,PS,DS,ZE,ZE,KR) D=DS+DCONV(KU)	60
С	0-D3+DCCHV(RU)	61
Č	VERIFY REGION	62
Č	TENTI / REGION	63
	IF (PS-PCH2) 120,120,150	64
15	0 IF (TS-TCH2) 170.170.160	65
16	0 KR=2	66 67
	GO TO 120	68
	0 KR=3	69
12	0 T=TS+TCONV(KU)	70
	RETURN	71
	END	72
418F C	TC TS+F1 FUNCTION TSHF(TS)	1
L	CCMMON/PHCALL/PS.HS .SS	2
	KR=0	3
	CALL DENSILITS.PS.DS.ZE.ZE.KR)	4
	CALL ENTH(1.TS.DS.HSC)	5 6
	T S HF= HSC	7
_	RETURN	8
C		9
	ENTRY TPSF(TS)	10
	KR = 0	11
	CALL DENS (1.TS.PS.OS.ZE .ZE .KR) CALL FNT(1.TS.DS.SSC)	12
	TPSF = SSC	
	* * * * * * * * * * * * * * * * * * *	13
		13 14
	TSHF=IPSF RETURN	13 14 15
	TSHF=IPSF	13 14

```
SIBFTC CPPRL1
      SUBROUTINE CPPRL(KU.T.D.CP.CV.GAMMA.C)
C
                    ------VERSION MARCH 1,1972-----
                                                                                 2
C
                                                                                 3
     THIS SUBROUTINE RETURNS THE FOLLOWING TO WASP IN USERS UNITS.
C
C
          SPECIFIC HEAT AT CONSTANT PRESSURE #CP
                                                                                 5
C
          SPECIFIC HEAT AT CONSTANT VOLUME
                                               =CV
                                                                                 6
C
          SPECIFIC HEAT RATIO
                                               =GAMMA
C
          SONIC VELOCITY
                                               = C
C
                                                                                 9
C
        THE PARTIALS PTV AND PDT EXPLAINED BELOW ARE RETURNED IN COMMON.
                                                                                10
(
                                                                                11
      COMMON/COCPO/
                        COC1.COC2.COC3
                                                                                12
                                                                     1
      COMMON/SICOF/ C1.C2.C3.C4.C5
                                                                                13
      COMMON /PARTLS/ PTV.PDT
                                                                                14
      COMMON/CONSTS/ TAUC.RHOA.RHOB.TAUA.E.R
                                                                                15
      COMMON/CONV4/SCONV(5)
                                                                                16
      COMMON/CONV5/CCONV(5)
                                                                                17
      COMMON/ [ERROR/IROUT
                                                                                18
      IRCUT=8
                                                                                19
      TS=TCHECK(KU.KR.T)
                                                                                20
      TT=1000-/TS
                                                                                21
      DS= DCHECK(KU.D)
                                                                                22
      CALL OMUSTIOS)
                                                                                23
      CALL OMUST2(TS)
                                                                                24
      CO2T2D=02T2D(TS)
                                                                                25
      COCALC=OCALC(TS)
                                                                                26
      CQCT=QDT(DS.TS)
                                                                                27
      CCTD=QTD(TS)
                                                                                28
      CQ2DT=Q2DT(DS.TS)
                                                                                29
      CQ202T=02C2T(DS.TS)
                                                                                30
           = -2.*C3*TT+C4/TT-C5- R*DS*TS*TS*C02T2D
     CV
                                                                                31
C--- PTV IS PARTIAL OF P BY T (NOT TAU)
                                                                                32
C--- FOT IS PARTIAL OF P BY RHO
                                                                                33
      PTV=R+DS+(1.+DS+(COCALC+DS+CODT-TS+(COTD+DS+CO2DT)))
                                                                                34
      PDT=R*TT*(1.+DS*(2.*COCALC+DS*(4.*CODT+DS*CQ2D2T)))
                                                                                35
      DhDT=-2.*C3*TT+C4/TT-C5+R*(1.+DS*(COCALC+DS*CODT-TS*(DS*CO2DT+
                                                                                36
     1COTD+TS+CO2T2D)))
                                                                                37
      DHDD=R*(TT*CQCALC+1000.*CQTD+DS*(TT*(3.*CQDT+DS*CQ2D2T)+1000.*
                                                                                38
     1CO2DT))
                                                                                39
      CP
           = DEDT-DHOC+(PTV/PDT)
                                                                                40
      GAMMA=CP/CV
                                                                                41
      CP=CP+SCONV(KU)
                                                                                42
      CV=CV+SCONV(KU)
                                                                                43
      GAMMAP=GAMMA + 10.+ PDT
                                                                                44
      CS=0.0
                                                                                45
      IF ( GAMMAP.GT. 0.0) CS=1000. + SQRT (GAMMAP)
                                                                                46
      C= CS+CCCNV(KU)
                                                                                47
      RFTURN
                                                                                48
      END
                                                                                49
```

SIBFIC SRINSB

```
SUBROUTINE SURF(KU, KR, TIN, SURFT)
C
         -----VERSION MARCH 1,1972-----
                                                                                  2
C
                                                                                  3
C
      THIS ROUTINE CALCULATES THE SURFACE TENSION OF LIQUID WATER AND
C
        THE LAPLACE CONSTANT
                                                                                   5
C
                                                                                  6
      COMMON/IERROR/IROUT
                                                                                  7
      COMMON/CCNV9/STCONV(5)
                                                                                  8
      COMMON /LAPLAC/ ALC
                                                                                  9
      DIMENSION A(5)
                                                                                 10
      DIMENSION X(5)
                                                                                 11
      DATA (A(I), I=1,5), B, TK /0.11609368 , 1.1214047 E-3, -5.7528052
                                                                                 12
     1E-6, 1.2862746 E-8, -1.1497193 E-11, 0.83, 647.30 /
                                                                                 13
C---UNITS OF G - M/S++2
DATA G / 9.80665 /
                                                                                 14
                                                                                 15
      IROUT=11
                                                                                 16
C---T IS DEG K
                                                                                 17
      TAU=TCHECK(KU,KR,TIN)
                                                                                 18
      T = 1000./TAU
                                                                                 19
      SURFT=0.0
                                                                                 20
      ALC=0.0
                                                                                 21
      IF (T.GT.TK) RETURN
                                                                                 22
      X\{1\} = TK-T
                                                                                 23
      X(2) = X(1) + X(1)
                                                                                 24
      X(3) = X(2) + X(1)
                                                                                 25
      X(4) = X(3) * X(1)
                                                                                 26
      X(5) = X(4) + X(1)
                                                                                 27
      Y = \{A(1) + X(2)\}/\{1.0 + B + X(1)\}
                                                                                 28
      DO 1 N=2,5
                                                                                 29
    1 Y = Y+A(N) + X(N)
                                                                                 30
      SURFT = Y
                                                                                 31
C--- UNITS OF SURFT MUST BE DYNE/CM
                                                                                 32
C--- UNITS OF ALC IS MM.
                                                                                 33
      TR= T/647.30
                                                                                 34
      IF (TR.GT. .998) 60 TO 2
                                                                                 35
      CALL DENS(KU, TAU, ZE, ZE, DL, DV, 1)
                                                                                 36
      ALC = SQRT (SURFT/ (G+ ABS (DL-DV)+1000. ) )
                                                                                 37
C---CONVERSION FACTOR FOR RESULTS TO BE IN MM AS IN THE TABLES
                                                                                 38
    2 ALC = ALC + 31.622777
                                                                                 39
      SURFT=SURFT+STCONV(KU)
                                                                                 40
      RETURN
                                                                                 41
      END
                                                                                 42
```

SIBFTC DTH

	FUNCTION DTHERM(XLM)	2
C	FUNCTION USED TO SOLVE EQ. (B52) FOR THERMAL CONDUCTIVITY	3
С	COMMON/ITERAT/TR, TO, T1, T2, T3, T4, T5, T6, T7, T8	5
	nougle precision to.tl.T2.T3.T4.T5.T6.T7.T8	6
	TCALC=(XLM*(XLM*(XLM*(XLM*(XLM*(XLM*(XLM*T8+T7)+T6)+T5)+T4)+T3)+	7
	1T2)+T1) *XLM+T0	8
		9
	DTHERM=TCALC-TR	10
	RETURN	11
	ENTRY DDTH(XLM)	12
С	TO ACCOUNT OF ACCOUNT MENTON PARTICON LICENTION	13
C	DERIVATIVE USED TO SOLVE EQ.(852) IN NEWTON RAPHSON ITERATION	14
C	The second section of the sect	15
	CDTH={XLM+(XLM+(XLM+(XLM+(XLM+(XLM+8.+T8+7.+T7)+6.+T6)+5.+T5)+	
	14.+T4)+3.+T3)+2.+T2)+XLM+T1	16
	DTHERM=DDTH	17
	RETURN	18
	FNO	19

```
SUBROUTINE THERM(KU, KR, PIN, TIN, DIN, EXCESK, TCOND)
                                                                                 1
C
        C
        SUBROUTINE CALCULATES THE THERMAL CONDUCTIVITY IN INTERNAL
C
          UNITS OF W/CM-K AND CONVERTS TO USERS UNITS
         EQUATIONS ARE THE INTERNATIONALLY AGREED UPON ONES IN REGIONS
                                                                                 6
         WHERE SAME ARE AVAILABLE AND ARE PROPOSED EQUATIONS IN OTHER
C
C
        REGIONS.
       THE NEAR SUBCRITICAL REGION IS THE AUTHORS FIT
                                                                                Q
                                                                                10
      COMMON/CONV8/KCONV(5)
                                                                                11
      COMMON/IERROR/IROUT
                                                                                12
      COMMON/ITERAT/TR, TO, T1, T2, T3, T4, T5, T6, T7, T8
                                                                                13
      REAL KCCNV
                                                                                14
      CCMMON /CRIT/ RHOCRT, PCRT, TCRT
                                                                                15
      CCMMON/TPARAM/TAU
                                                                                16
      EXTERNAL DTHERM, DDTH
                                                                               17
      DIMENSION CFC(5.2)
                                                                                18
      DATA CFC/-.57861540,1.45746404,.17006978,.13348045, .32783991E-1,
                                                                               19
     1-.70859254,.94131399,.64264434E-01,1.85363188,1.98065901/
                                                                                20
      DOUBLE PRECISION PROP
                                                                                21
      DOUBLE PRECISION A5(5), B5(4), C5(4), T1, SUM1, SUM2, SUM3
                                                                               22
      DATA AD, A1, A2, A3, A4/-.17384732, .82350372, -1.55213983, -.12626138,
                                                                               23
     1 2.83922425 /
                                                                                24
      DATA A5 / -.92247000C0 , 6.728934102 , -10.11230521, 6.996953832,
                                                                               25
            -2.316062510 / , B5 / -.2095427600, 1.320227345,
     1
                                                                               26
     2
            -2.485904388, 1.517081933 / ,
                                                                               27
            C5 / .08104183147, -.4513858027 ,.8057261332,-.4668315566 /
                                                                               28
      DOUBLE PRECISION A10(2),B10(2),C10(3),D10(6),A,B,C,T11,T22,T33
                                                                               29
      DATA A10 / .01012472978, .05141900883 /.810 /663742.6916,
                                                                               30
     1 1.388806409 / , C10 / 338855.7874, 576.8000000, .2060000000 /,
                                                                               31
     2 010 / .000002100200454, 23.94090099, 3.458000000,13.63235390 ,
                                                                               32
            .01360000000, .007852600000 /
                                                                               33
      DOUBLE PRECISION A8(9),88(9),C8 ,E9(3),T0,T2,T3,T4,T5,T6,T7,T8
      DATA A8 / 1.365350409, -4.802941449, 23.60292291, -51.44066584, 38.86072609, 33.47617334,-101.0369288, 101.2258396, -45.69066893 / ,
                                                                               35
     1
                                                                               36
     2
                                                                               37
     3
            88 / 1.514476538, -19.58487269, 113.6782784, -327.0035653,
                                                                               38
                397.3645617, 96.82365169,-703.0682926, 542.9942625,
-85.66878481 / , C8 / 1.017179024 /
                                                                               39
                                                                               40
      DATA E9 / 50.60225796 , -105.6677634 , 55.96905687 /
                                                                               41
      IROUT=10
                                                                               42
      PMN=PCHECK(KU, KR, PIN)
                                                                               43
      TAU=TCHECK(KU, KR, TIN)
                                                                               44
      DS=DCHECK(KU,DIN)
                                                                               45
C
         CONVERT TAU AND PMN TO VARIOUS UNITS
                                                                               46
      TK=1000./TAU
                                                                               47
      TR = TK/TCRT
                                                                               48
      T = TK-273.15
                                                                               49
      PBAR = PMN*10.
                                                                               50
      PR=PMN/PCRT
                                                                               51
C---CUT OF RANGE CHECK ON PRESS AND TEMP.
                                                                               52
      IF (PBAR.LT. 1.0 .OR. PBAR.GT.500.) WRITE(6,151) TIN, PIN
                                                                               53
      IF (T.LT.0.0.OR.T.GT.700.) WRITE(6,151) TIN,PIN
                                                                               54
  151 FORMAT (1HO, 5H T =,F12.4,8H OR P =,F12.4, 64HIS OUT OF RANGE,
                                                                              55
     1RETURNED THERMAL CONDUCTIVITY IS EXTRAPOLATED )
                                                                               56
C
                                                                               57
C
        CHECK FOR REGION I
                                                                               58
C
                                                                               59
      IF (T.LE.350..AND.DS.GT.RHOCRT) GO TO 100
                                                                               60
C
                                                                               61
```

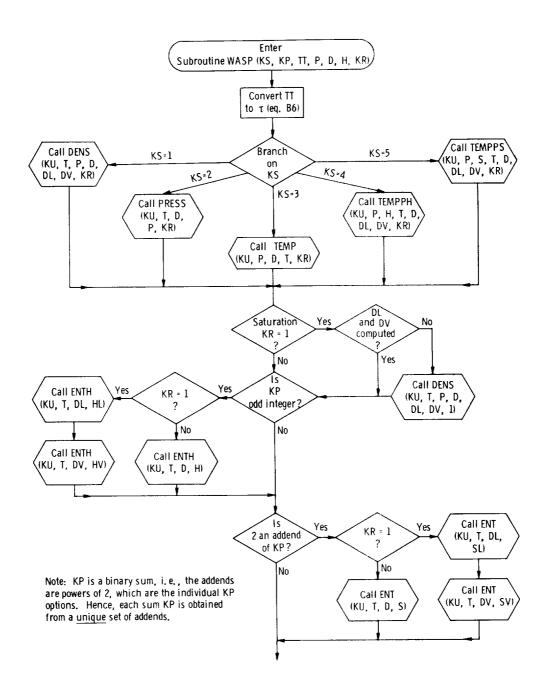
```
C
       CHECK FOR JAGGED LOWER BOUNDARY OF REGION ILLOR UPPER PART
                                                                                 62
C
         OF REGION II
                                                                                 63
C
                                                                                 64
      IF (PBAR.GT.450..AND.T.LT.550.) GO TO 80
                                                                                 65
      IF (PBAR.GT.350..AND.T.LT.500.) GO TO 80
                                                                                 66
      IF (PBAR.GT.275..AND.T.LT.450.) GO TO 80
                                                                                 67
      IF (PBAR.GT.225..AND.T.LT.425.) GO TO 80
                                                                                 68
      IF (PBAR.GT.175..AND.T.LT.400.) GO TO 80
                                                                                 69
C
                                                                                 70
       EQUATION (840) FOR P=1.0 BARS
C
                                                                                 71
                                                                                 72
   10 V1 = (17.6 +.0587*T+.000104*T*T -4.51E-08*T*T*T)/1000.
                                                                                 73
      IF (PBAR.GT.1.000) GO TO 20
                                                                                 74
      TCOND=V1+KCONV(KU)
                                                                                 75
      GO TO 500
                                                                                 76
C
                                                                                 77
       EQUATION (846) FOR REGION II.
                                                                                 78
   20 ANS=((103.51+.4198*T-2.771E-05*T*T)*DS+2.14821E+14/(T**4.2)*DS*DS
                                                                                 79
     13/1000.+V1
                                                                                 80
      TCOND=ANS+KCONV(KU)
                                                                                 81
      GO TO 500
                                                                                 82
C
                                                                                 83
C
                   REGION I CALCULATIONS
                                                                                 84
C
                                                                                 85
  100 CALL PSSS(PS)
                                                                                 86
      PREDD = (PMN-PS)/PCRT
                                                                                 87
      SUM1=(((A5(5)+TR+A5(4))+TR+A5(3))+TR+A5(2))+TR+A5(1)
                                                                                 88
      $UM2=((B5(4)+TR+B5(3))+TR+B5(2))+TR+B5(1)
                                                                                 89
      $UM3=((C5(4)+TR+C5(3))+TR+C5(2))+TR+C5(1)
                                                                                 90
      TCOND=(SUM1 + (SUM3*PREDD + SUM2)*PREDD )*KCONV(KU)
                                                                                 91
      GO TO 500
                                                                                 92
                                                                                 93
C
       CHECK FOR REGION III-USING BOUNDARY EQUATION (854) WHICH DIVIDES
                                                                                 94
C
         REGIONS III AND IV.
                                                                                 95
     THEN SEPARATE HATCHED REGION WHERE NO EQUATION EXISTS FROM REMAINDER
                                                                                 96
C
         OF REGION IV
                                                                                 97
   80 IEQUA=10
                                                                                 98
      IF(T.GT.450.) GO TO 300
                                                                                 99
      PBOUND=E9(1)+E9(2)*TR+E9(3)*TR*TR
                                                                                100
      IF (PR.LT.PBOUND) GO TO 300
                                                                                101
      IF(TK.LT.TCRT.AND.DS.LT.RHOCRT) GO TO 400
                                                                                102
      IEQUA=8
                                                                                103
C
                                                                                104
Č
                   EQUATION (B52) IS SOLVED BY ITERATION
                                                                                105
C
                                                                                106
  200 MTR=0
                                                                                107
      PRDP=PR
                                                                                108
      CON=PRDP-C8
                                                                                109
      TO =
            A8(1)+ CON+B8(1)
                                                                                110
             A8(2)+ CON+B8(2)
      71 =
                                                                                111
             AB(3)+ CON+BB(3)
      T2 =
                                                                                112
      T3 =
             A8(4)+ CON+B8(4)
                                                                                113
      T4 =
             A8(5)+ CON+B8(5)
                                                                                114
             A8(6)+ CON*88(6)
      T5 =
                                                                                115
             A8(7)+ CON+B8(7)
      76 =
                                                                                116
      77 =
             A8(8)+ CON+B8(8)
                                                                                117
      T8 =
             A8(9)+ CON+B8(9)
                                                                                118
C
      USE CONDUCTIVITY BASEC ON BOUNDARY AS INITIAL ESTIMATE
                                                                                119
      PPR = PR
                                                                                120
      PR=PBOUND
                                                                                121
      GO TO 300
                                                                                122
```

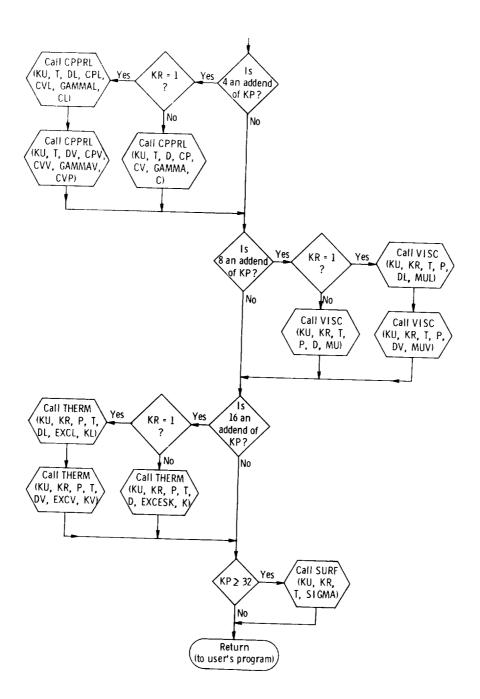
```
210 PR=PPR
                                                                                123
       XHI = .55
                                                                                124
       X=(ANS*3.+XHI*2.)/5.
                                                                                125
       IF(PR.LE.1.05.AND.TR.LE.1.05) X=ANS+.005
                                                                                126
       TCOND=SOLVE(X,DTHERM,CDTH) *KCONV(KU)
                                                                                127
C
                                                                                128
C
        THIS EQUATION DOES NCT ALWAYS CONVERGE NEAR THE BOUNDARY WHERE
                                                                                129
C
          IT SHOULD. SWITCH TO AUTHORS EXTRAPOLATION IF THIS HAPPENS.
                                                                                130
C
                                                                                131
       IF (TCCND.LE.O.O) GO TO 400
                                                                                132
      GO TO 500
                                                                                133
  300 DON=1.0D+0
                                                                                134
      B=(B10(1) *PR**1.63) / (CON+B10(2) *PR**3.26)
                                                                                135
      C = (C10(1) *PR**1.5 + C10(2)) / B - C10(3)
                                                                                136
      CSP≠C
                                                                                137
      TEST = DCN-B*D10(1)/TR**7
                                                                                138
      T11=(A10(1)*PR+A10(2))*TR**1.445/TEST**CSP
                                                                                139
      T22= D10(2)*PR**4 *EXP(-9.0*D10(3)*(TR-1.0))/(D0N+D10(4)
                                                                               140
                /PR**12)
                                                                               141
      T33 = D10(5) - D10(6) *PR *EXP(-D10(3) * (TR-1.0))
                                                                                142
      ANS = T11 + T22*T33
                                                                                143
      IF (IEQUA.EQ.8) GO TO 210
                                                                                144
      TCOND=ANS+KCONV(KU)
                                                                                145
      GO TO 500
                                                                                146
       HATCHED REGION WHERE NO EQUATION EXISTS IN THE REFERENCES.
C
                                                                                147
           AUTHORS OWN EQ USED HERE WITH 1 BAR EQ.
                                                                                148
  400 V1 = (17.6 +.0587*T+.000104*T*T -4.51E-08*T*T*T)/1000.
                                                                                149
      XX= ALOGIO(DS/RHOCRT)
                                                                                150
      KJ=1
                                                                                151
      IF (XX.GT.-.39794) KJ=2
                                                                                152
      Y=CFC(1,KJ)+(((CFC(5,KJ)*XX+CFC(4,KJ))*XX+CFC(3,KJ))*XX
                                                                               153
     1 +CFC(2, KJ)) *XX
                                                                               154
      TCOND=(10. **Y+V1) *KCONV(KU)
                                                                                155
  500 CCNTINUE
                                                                               156
C
                                                                               157
       REACTING CONDUCTIVITY IN THE NEAR CRITICAL REGION BY SENGERS
C
                                                                               158
C
                                                                               159
      DRHCC = ABS ( DS - RHCCRT ) / RHCCRT
                                                                               160
      DELAMB=0.
                                                                                161
      IF( DRHOC.GT. .6) GO TO 520
                                                                                162
      DELTC = ABS (TR-1.)
                                                                                163
      RAT = DS/RHCCRT
                                                                                164
      IF (DRHOC.LT.1.E-4) GC TO 510
                                                                               165
      IF (DELTC.LT.1.E-7) GO TO 502
                                                                               166
      XBETA = DELTC**.35/DRFOC
                                                                                167
      IF (XBETA.GT..4) GO TO 506
                                                                               168
  502 DELAMB= 11.6E-5 / (SQRT(RAT)+DRHOC++1.71)
                                                                               169
      GC TO 520
                                                                               170
  506 IF (XBETA.GT.3.) GO TC 510
                                                                               171
      XB= ALOG10(XBETA)
                                                                               172
      ARAT= (({A4*XB+A3}*XB+A2)*XB+A1)*XB+A0
                                                                               173
      DELAMB=11.6E-5/(SQRT(RAT) DELTC++.6) +10.4+ARAT
                                                                               174
      GC TO 520
                                                                               175
 510 IF (DELTC.LT.1.E-7) GO TO 525
                                                                               176
      DELAMB = 11.6E-5/(SQRT(RAT)+DELTC++.6)
                                                                               177
 520 EXCESK= DELAMB
                                                                               178
      RETURN
                                                                               179
 525 EXCESK =1.E30
                                                                               180
     RETURN
                                                                               181
     END
                                                                               182
```

```
SIBETC DYVISC
      SUBROUTINE VISCIKU. KR. TIN. PIN. DIN. SVISC)
ſ
        C
                                                                               3
       CALCULATE THE VISCOSITY GIVEN TAU.P. AND D IN USER-S UNITS KU.
C
C
                  ANSWER RETURNED IN USER-UNITS IN SVISC.
C
      COMPON/TERROR/TROLT
                                                                               7
      COMMON/CRIT/ RHCCRT.PCRT.TCRT
                                                                               8
      CCMMON /TPARAM/ TIN
                                                                               Q
      COMMON/CONVT/MCONV(5)
                                                                              10
      REAL MCCNV
                                                                              11
      DIMENSILN A(5),8(3),C(3),D(3),COF(5,2)
                                                                              12
      DATA (A(I).I=1.5) /241.400C.0.38282095.0.21628302.0.1498694.
                                                                              13
     1
                         0-47118801 /
                                                                              14
     2
                (B([)·[=1.3) /263.4511.0.4219836.80.4000 /
                                                                              15
     3
               (C(1),1=1,3) / 586.11987, 1204.75394, 0.4219836 /.
                                                                             16
              (D(1), I=1.3) / 111.35647, 67.320801, 3.2051470 /
                                                                             17
     DATA COF/-6.4556581.1.3949436..30259083..10960682..15230031E-01.
                                                                             18
     1-6.4608381 .1.61633210.1.07097705.-13.938.30.119832 /
                                                                              19
      IROUT=9
                                                                              20
[---
                                                                              21
C---TK IS DEG K. T IS DEG C. TR IS REDUCED TEMP
                                                                              22
      TK=1000./TCHECK(KU.KR.TIN)
                                                                              23
      T = TK - 273.15
                                                                              24
      TR=[K/TCRT
                                                                              25
C---P IS BARS. PMN IS NEGA NEWTONS/M#M .PR IS REDUCED PRESSURE
                                                                              26
      PMN=PCHECK(KU.KR .PIN)
                                                                             27
      P = 10.0*PMN
                                                                             28
      PR=FMN/PCRT
                                                                             29
C--- DD IS G/CC. SPVR IS REDUCED SPECIFIC VCLUME.
                                                                             30
      DD=DCHECK(KU.DIN)
                                                                             31
      SPVR= RHOCRT/DD
                                                                             32
(
                                                                             33
    CHECK FOR CUT OF RANGE ON P AND T
                                                                             34
                                                                              35
      IF ( P .LT. .99 .OR. P .GT. 800.01) WRITE(6,101) T.P.
                                                                             36
      IF ( T .GT. 800.0 .OR. T .LT. 0.0 ) WRITE(6.101) T.P
                                                                             37
  101 FORMAT(1H .48H OUT OF RANGE. ANSWER IS EXTRAPOLATED FOR T=
                                                                             38
     1.F12.4. 4H P= .F12.4)
                                                                             39
      IF (DD-GT-RHOCRT-AND-T-LT-300-) GO TO 100
                                                                             40
      GO TO 110
                                                                             41
C
                                                                             42
C
                  REGION I
                                                                             43
C---FOR TEMP-- 0 TO 300 CENT AND PRES--PSAT TO 800 BAR
                                                                             44
                                                                             45
 100 \times 1 = 10.0 **(A(2)/(TR-A(3))
                                                                             46
     CALL PSSS(PSS)
                                                                             47
      PSR=PSS/PCRT
                                                                             48
      X2 = 1.0 + (PR-PSR)*A(4)*(TR-A(5))
                                                                             49
      SVISC = (A(1) *x1 *x2 )/10.0**6 *MCONV(KU)
                                                                             50
      RETURN
                                                                             51
C
                                                                             52
     CALCULATE VISCOSITY FOR 1.0 BAR NEEDED FOR REGIONS II.III.IV
ſ
                                                                             53
                                                                             54
  110 VISC1=(R(1)+(TR-B(2))+8(3))
                                                                             55
      IF (P.LE.1.0) GO TO 1000
                                                                             56
C
                                                                             57
C
     CHECK FOR TEMPERATURE HANGE WHERE NO CURVE EXISTS
                                                                             58
C
                                                                             59
      IF (T.GE.300..AND.T.LT.374.15) GD TO 400
                                                                             60
      IF (DD-LT-RHOCRT-AND-T-LT-300-) GO TO 200
                                                                             61
      GC TO 300
                                                                             62
```

```
•
                                                                                 63
                  REGION II
                                                                                 64
C--- FOR PRES-- 1 TO PSAT BAR AND 100 TO 300 CENT
                                                                                 65
C
                                                                                 66
  200 SVISC = (VISC1 - 1.0/SPVR+(C(1)-C(2)+(TR-C(3))))/10.++6+MCONV(KU)
                                                                                 67
      RETURN
                                                                                 68
•
                                                                                 69
C
                 REGION III
                                                                                 70
C---FOR PRES -- 1 TO 800 BAR AND 375 TO 800 CENT
                                                                                 71
C
                                                                                 72
  300 SVISC =(VISC1 + D(1)/SPVR +D(2)/(SPVR*SPVR) + D(3)/(SPVR*SPVR*SPVR
                                                                                 73
     1 ) //10-0++6 +MCONV(KU)
                                                                                 74
      RETURN
                                                                                 75
C
                                                                                 76
C
     AUTHORS EXTRAPOLATION USED FOR REGION IV
                                                                                 77
C
                                                                                 78
  400 X=ALOG10(1./SPVR)
                                                                                 79
      KJ=1
                                                                                 80
      IF (X.GT.--12493873) KJ=2
                                                                                 81
      Y= X+(X+(X+COF(5+KJ)+COF(4+KJ))+COF(3+KJ))+COF(2+KJ))+COF(1+KJ)
                                                                                 82
      SVISC=(VISC1/1.E6+10.**(Y+1.)/.0192)*MCONV(KU)
                                                                                 83
      RETURN
                                                                                 84
 100C SVISC=VISC1/10.**6*MCONV(KU)
                                                                                 85
      RETURN
                                                                                 86
      END
                                                                                 87
```

FLOW CHART FOR SUBROUTINE WASP





APPENDIX F

TEST PROGRAM WITH OUTPUT

The following tables have been generated by WASP to facilitate comparing results to the ASME Tables (ref. 1) and the International Skeleton Tables (refs. 1 and 2). No attempt was made to reproduce the entire reference tables; only a select number of points were chosen at even intervals representative of the total range. The values in the following tables are in the same units and similar form as the reference tables. Results of comparisons between the calculated and the tabulated values are discussed in the main part of the text.

SIBFTC MTWASP

```
COMMON/PROPTY/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
     IGAMHAL, GAMMAY, C, CL, CVP, MU, MUL, MUY, K, KL, KY, SIGMA, EXCL, EXCV, EXCESK
                                                                                    3
      DIMENSION PSIA(12), TF(11), VOL(12,11), HOUT(12,11), SOUT(12,11)
                                                                                    4
      DIMENSION PBARTC(13), TCOUT(20, 13), TCOUT2(31, 13)
      REAL MU, MUL, MUV, K, KL, KV
      DIMENSION T(200), P(200), VL(200), HVOUT(200), SVOUT(200), HLOUT(200)
                                                                                     7
     1,SLOUT(200),VV(200)
                                                                                     8
      DIMENSION PNEAR(12), TNEAR(6)
                                                                                    9
      COMMON/LAPLAC/ALC
                                                                                    10
      DIMENSION PCP(12),TCP(5),CPARY(12,5)
      DIMENSION PBAR(7), TCENT(20), VOUT(20,7), PSVS(15), TFVS(31), VOUT2(31,
                                                                                    11
                                                                                    12
     1151
                                                                                    13
       MASTER TEST PROGRAM FOR WATER AND STEAM PROPERTY PACKAGE
                                                                                    14
                                                                                    15
C
                                                                                    16
       PART 1
                                                                                    17
C
      COMPARE SATURATION PROPERTIES OF ASME STEAM TABLES PAGES 83-88
                                                                                    18
C
       AS A FUNCTION OF TEMPERATURE 35-705F IN INCREMENTS OF 10F
                                                                                    19
                                                                                    20
                                                                                    21
      KU=3
                                                                                    22
      NPT=1
                                                                                    23
      T1=494.
                                                                                    24
   10 KR=1
                                                                                    25
      P1=0.0
                                                                                    26
       CALL WASP(1,3,T1,P1,RHO,H,KR)
                                                                                    27
       T(NPT)=T1-460.
                                                                                    28
       P(NPT)=P1
                                                                                    29
       VL(NPT)+1./OL
                                                                                    30
       VV(NPT)=1./DV
                                                                                    31
       SLOUT(NPT)=SL
                                                                                    32
       SYDUT(NPT)=SV
                                                                                    33
       HLOUT(NPT)=HL
                                                                                    34
       HVOUT(NPT)=HV
```

```
NPT=NPT+1
                                                                                    35
        T1=T1+12.0
                                                                                    36
        IF (T1.LE.1165.) GO TC 10
                                                                                    37
        NPT=NPT-1
                                                                                    38
                                                                                    39
         PRINT SATURATION RESULTS
                                                                                    40
        WRITE(6,1)
      1 FORMAT(1H1,51H COMPARABLE TO ASME TABLE NO. 1 PAGES 83-88
                                                                                    41
                                                                            )
        WRITE(6,2)
                                                                                    42
                                                                                    43
        NLIN=0
                                                                                    44
        DO 20 J=1,NPT
                                                                                    45
        JJ=NPT-J+1
                                                                                    46
        NLIN=NLIN+1
        WRITE(6,3) T(JJ),P(JJ),VL(JJ),VL(JJ),HLDUT(JJ),SLOUT(JJ)
                                                                                   47
                                                                                   48
       1,SVOUT(JJ)
                                                                                   49
        IF (NLIN.LT.50) GO TO 20
                                                                                   50
        NLIN=0
                                                                                   51
        WRITE(6,1)
                                                                                   52
       WRITE(6;2)
                                                                                   53
      2 FORMAT(1HO,90H T-F
                              P-PSIA
                                        VL.
                                              FT3/LBM
                                                          ٧V
                                                                       BTU/L
                                                                 HL
                                                                                   54
                     SL BTU/LBM-R SV
      1 A M
           HV
                                                           )
     3 FORMAT(1H F5.0,F10.4,2F12.6,2F12.3,2F12.4)
                                                                                   55
                                                                                   56
    20 CONTINUE
                                                                                   57
        WRITE(6.21)
                                                                                   58
    21 FORMAT(1H1)
                                                                                   59
 C
                                                                                   60
 C
                 ASME TABLE NO. 3 PAGES 97-203
 C
                                                                                   61
       PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER
 C
                                                                                   62
 C
                                                                                   63
            TABLE IS 2 PAGES 32-750F AND 750-1500F
            FOR EACH SET OF ISOBARS
 C
                                                                                   64
        WILL COMPARE 12 ISOBARS FOR VARIOUS TEMPERATURES
                                                                                   65
 C
 C
                                                                                   66
                                                                                   67
       DATA PSIA/1.0,5.0,25.,100.,200.,500.,1000.,1500.,2000.,5000.,10000
                                                                                   68
      1.,14500./
       DATA TF/32.,50.,100.,150.,300.,500.,700.,900.,1100.,1300.,1500./
                                                                                   69
                                                                                   70
       DO 50 I=1,11
                                                                                   71
       TIN=TF(1)+460.
       CO 45 J=1,12
                                                                                   72
                                                                                  73
       KR=0
                                                                                  74
       KU= 3
                                                                                  75
       CALL WASP(1,3,TIN,PSIA(J),D,H,KR)
                                                                                  76
       IF (KR.EQ.1) GO TO 45
                                                                                  77
       VOL(J,I)+1./D
                                                                                  78
      H=(1,L)TUOH
                                                                                  79
       S=(1,L)TUD2
   45 CONTINUE
                                                                                  80
                                                                                  81
   50 CONTINUE
                                                                                  82
       WRITE(6,41 )
                                                                                  83
      WRITE(6,42)
                                                                                  84
      DO 60 J=1,12,3
                                                                                  85
      WRITE(6,44) PSIA(J), PSIA(J+1), PSIA(J+2)
                                                                                  86
      00 60 I=1,11
      WRITE(6,43) TF(I), VOL(J, I), HOUT(J, I), SOUT(J, I), VOL(J+1, I), HOUT(J+1
                                                                                  87
     1,I),SOUT(J+1,I),VOL(J+2,I),HOUT(J+2,I),SOUT(J+2,I)
                                                                                  88
   41 FORMAT(1H1,20X,36H COMPARISON POINTS FOE TABLE NO.3
                                                                                  89
   42 FORMAT (1HO, 20X, 47H (VOLUME, ENTHALPY, ENTROPY) FOR PRESSURE LISTED )
                                                                                  90
   43 FORMAT(1H ,F6.0,3(F12.5,F11.2,F10.4,5X))
                                                                                  91
                                                                                  92
   44 FORPAT(1H0,6X,3(F10.0,4HPSIA,20X))
                                                                                  93
   60 CONTINUE
                                                                                  94
C
                                                                                  95
C
       PART 3 ASME TABLE NC. 4 PAGES 208-220
C
                                                                                  96
                                                                                  97
C
       PROPERTIES OF SUPERHEATED STEAM AND COMPRESSED WATER IN
C
                                                                                 98
       THE CRITICAL REGION
                                                                                 99
C
      DATA PNEAR/2860.,3000.,3060.,3100.,3160.,3200.,3260.,3400.,3500.,
                                                                                100
     13600.,3800.,3960./
                                                                                101
                                                                                102
```

```
103
     DATA TNEAR/650.,680.,710.,740.,770.,800./
                                                                               104
     CC 80 I=1,6
                                                                               105
     TIN=TNEAR(I)+46C.
                                                                               196
     CC 70 J=1,12
                                                                               107
     KR=0
                                                                               108
     CALL WASP(1,3,TIN,PNEAR(J),D,H,KR)
                                                                               109
     VOL(J,1)=1./D
                                                                               110
     IF (KR.EQ.1) GO TO 70
                                                                               111
     HCUT(J,I)=H
                                                                               112
     SCUT(J,I)=S
                                                                               113
  70 CCNTINUE
                                                                               114
  80 CONTINUE
                                                                               115
     WRITE(6,81)
  81 FORMAT(1H1,20X,40H CCMPARISON POINTS FOR ASME TABLE NO. 4
                                                                               116
                                                                               117
     CO 90 J=1,12,3
                                                                               118
  82 FCRMAT(1H0,20X,47H (VCLUME,ENTHALPY,ENTROPY) FOR PRESSURE LISTED )
                                                                               119
                                                                                120
      WRITE(6,44) PNEAR(J), PNEAR(J+1), PNEAR(J+2)
                                                                                121
      CC 90 1=1,6
      WRITE(6,43) THEAR(I), VCL(J,I), HOUT(J,I), SOUT(J,I), VOL(J+1,I), HOUT(
                                                                                122
    1J+1,I),SOUT(J+1,I),VOL(J+2,I),HOUT(J+2,I),SOUT(J+2,I)
                                                                                123
                                                                                124
   90 CONTINUE
                                                                                125
C
                                                                                126
       PART 4 ASME TABLE NC. 9 PAGES 278-279
      DATA PCP/1.,4.,10.,30.,60.,100.,200.,400.,1000.,3000.,6000.,10000
                                                                                127
                                                                                128
     1./
                                                                                129
      DATA TCP/32.,300.,700.,1100.,1500./
  109 FORMAT(1H1,20X,42H COMPARISON POINTS FOR ASME TABLE NO. 9
                                                                                130
                                                                                131
      WRITE(6,109)
  111 FORMAT(1H/,4HPSIA,12(4X,F6.0)/1H0,4HTEMP/,3H F /)
                                                                                132
                                                                                133
      WRITE(6,111) PCP
                                                                                134
      DC 120 I=1.5
                                                                                135
      TIN=TCP(1)+460.
                                                                                136
      CC 110 J=1,12
                                                                                137
      KR = C
                                                                                138
      CALL WASP(1,4,TIN,PCP(J),D,H,KR)
                                                                                139
      CPARY(J.I)=CP
                                                                                140
  110 CCNTINUE
                                                                                141
       WRITE(6,112) TCP(I),(CPARY(J,I),J=1,12)
                                                                                142
  120 CONTINUE
                                                                                143
  112 FCRMAT(1H0,F5.0,12F10.3)
                                                                                144
                                                                                145
             PART 5 VISCOSITY CHECKOUT
C
                                                                                146
C
                                                                                147
       DATA PBAR/1.,50.,200.,350.,500.,650.,800./
      DATA TCENT/10.,50.,100.,120.,140.,160.,180.,200.,220.,240.,260.,
                                                                                148
                                                                                 149
      1280.,300.,320.,340.,360.,400.,500.,600.,700./
      DATA PSVS/1.,2.,5.,10.,20.,50.,100.,200.,500.,1000.,2000.,5000.,
                                                                                 150
                                                                                 151
      17500.,10000.,12000./
       DATA TEVS/1500.,1450.,1400.,1350.,1300.,1250.,1200.,1150.,1100.,
                                                                                 152
      11050.,1000.,950.,900.,850.,800.,750.,700.,650.,600.,550.,500.,
                                                                                 153
                                                                                 154
      2450.,400.,350.,300.,250.,200.,150.,100.,50.,32./
                                                                                 155
       WRITE(6,500)
                                                                                 156
       KL=1
                                                                                 157
       CC 300 J=1.7
                                                                                 158
       PIN=PBAR(J)/10.
                                                                                 159
       CO 300 I=1,20
                                                                                 160
       TIN=TCENT(I)+273.15
                                                                                 161
       KR = C
                                                                                 162
       CALL WASP(1,8,TIN,PIN,C,H,KR)
                                                                                 163
       IF (KR.EQ.1) GC TO 300
                                                                                 164
       VCUT(I,J)=#U*1.E5
                                                                                 165
   3CC CONTINUE
                                                                                 166
       WRITE(6,301)
                                                                                 167
       WRITE(6,302) PBAR
                                                                                 168
       CC 320 I=1,20
                                                                                 169
   32C WRITE(6,303) TCENT(1), (VCUT(1,J),J=1,7)
   301 FCRMAT(1H1,42H VISCOSITY TABLE-INTERNATIONAL BOOK
                                                                                 170
```

```
3C2 FORMAT(1H0,7(8X,F6.0,4HBARS ))
                                                                                 171
   303 FORMAT(1HO,F5.0,7(F12.2.6X))
                                                                                 172
       WRITE(6,500)
                                                                                 173
       KU=3
                                                                                 174
       CO 350 J=1,15
                                                                                 175
       PIN=PSVS(J)
                                                                                 176
       DO 350 [±1,31
                                                                                 177
       TIN=TFVS(1)+460.0
                                                                                 178
       KR=0
                                                                                 179
       CALL WASP(1,8,TIN,PIN,D,H,KR)
                                                                                 180
       IF (KR.EQ.1) GO TO 350
                                                                                 181
 C
            THIS CONVERSION GETS FROM UINTS=3 OF PROGRAM TO UNITS OF TABL
                                                                                 182
       VQUT2(I,J)=HU+1.E6+1.4881639/4.7880258
                                                                                 183
   350 CONTINUE
                                                                                 184
       WRITE(6,351)
                                                                                 185
       WRITE(6,352) PSVS
                                                                                 186
       00 355 I=1,31
                                                                                 187
       WRITE(6,353) TFVS(I), (VOUT2(I,J), J=1,15)
                                                                                 188
   355 CONTINUE
                                                                                 189
   351 FORMAT(1H1,45H VISCOSITY-ASME TABLE NO. 10 PAGE 280
                                                                                 190
  352 FORMAT(1H0,5H PSIA,2X,15F8.0,/,5H0 T-F )
                                                                                 191
   353 FORMAT(1H ,2X,F6.0.15F8.2)
                                                                                 192
C
                                                                                 193
C
        PART 6
                 THERMAL CONCUCTIVITY CHECKOUT
                                                                                 194
C
                                                                                 195
   360 CONTINUE
                                                                                 196
       DATA PBARTC/1.,10.,25.,50.,100.,150.,200.,250.,300.,350.,400.,450.
                                                                                 197
      1.500./
                                                                                 198
       WRITE(6,500)
                                                                                 199
       KU=1
                                                                                 200
      DO 400 J=1,13
                                                                                 201
       PIN=PBARTC(J)/10.
                                                                                 202
       DO 400 I=1,20
                                                                                 203
      TIN=TCENT(1)+273.15
                                                                                 204
       KR=0
                                                                                 205
      CALL WASP(1,16,TIN,PIN,D,H,KR)
                                                                                 206
       IF (KR.EQ.1) GO TO 400
                                                                                 207
      TCOUT(I,J)=K+1.E4
                                                                                 208
  400 CONTINUE
                                                                                 209
      WRITE(6,401)
                                                                                 210
      WRITE(6,402) PBARTC
                                                                                 211
      DO 420 I=1,20
                                                                                212
  420 WRITE(6,403) TCENT(I),(TCOUT(I,J),J=1,13)
                                                                                 213
  401 FORMAT(1H1,46H THERMAL CONDUCTIVITY - INTERNATIONAL BOOK
                                                                                214
  402 FORMAT(1H0,6HP-BARS,13(2X,F7.0)/1H0,3HT-F)
                                                                                 215
  403 FORMAT(1H0,F5.0,13F9.2)
                                                                                216
      WRITE(6,500)
                                                                                217
      KU×3
                                                                                218
      CO 450 J=1,13
                                                                                219
      PIN = PSVS(J)
                                                                                220
      DO 450 I=1,31
                                                                                221
      TIN = TFVS(I)+460.0
                                                                                222
      KR=0
                                                                                223
      CALL WASP (1,16,TIN,PIN,D,H,KR)
                                                                                224
      IF(KR.EQ.1) GO TO 450
                                                                                225
      TCOUT2(I,J) = K + 1.E3 + 3600.
                                                                                226
  450 CONTINUE
                                                                                227
      WRITE(6,451)
                                                                                228
      WRITE(6,352)(PSVS(I),I=1,13)
                                                                                229
      CO 455 I=1,31
                                                                                230
  455 WRITE(6,353) TFVS(I),(TCOUT2(I,J),J=1,13)
                                                                                231
  451 FORMAT(1H1,20X,47H THERMAL CONDUCTIVITY-ASME TABLE NO.11 PAGE 281)
                                                                                232
C
                                                                                233
C
      SURFACE TENSION
                        AND LAPLACE CONSTANT
                                                    INTERNATIONAL BOOK
                                                                                234
C
                  PAGE 172 - TABLE 7
                                                                                235
C
                                                                                236
      WRITE(6,481)
                                                                                237
      KU=1
```

4	DU 480 J=1,16 TI = TCENT(J)+27; CALL WASP(1,32, 80 WRITE(6,482) TC 81 FORMAT(1H1,20X,7; 110N AND LAPLACE (82 FORMAT(1H , F7.0	TI,PI,D ENT(J), 5H INTE CONSTAN	SIGMA,ALC RNATIONAL BOOM T /1H0,24H	(TABLE NO.7. T-C DYNE/CM	SURFACE MM	TENS	239 240 241 242 243 244 245 246
C C	END	TEST	PROGRAM				247 248
5	OO FORMAT(1H1) STOP						249 250 251

COMPARISON POINTS FOR ASME TABLE 1, REF. 1

Sturmered Study Stud	ture.					Cotoreston	
0.028918 0.0160642 75.559 1010-910 0.9893 0.026793 0.126985 715.057 1007.180 0.0993 0.026773 0.107086 75.559 1006.104 0.9996 0.026773 0.107085 711.164 1107.807 0.9196 0.026773 0.126985 711.164 1107.807 0.9196 0.026773 0.126985 111.164 1107.807 0.9196 0.026773 0.126985 111.164 1107.807 0.9196 0.026773 0.026773 0.02774 0.02774		Saturated 11qu1d	Φ .	Saturated 11qu1d	Saturated vapor	liquid	Saturated vapor
0.02855 0.12695 735.059 1000.104 0.9398 10.02895 0.12695 735.075 1007.88 0.9398 10.02895 0.12695 0.12695 735.075 1007.88 0.9398 0.02895 0.12695 0.12695 711.164 1137.007 0.8999 0.02834 0.131348 0.69146 1134.047 0.8999 0.02834 0.28772 0.691246 0.28772 0.02833 0.28772 0.28772 0.02833 0.28772 0.28	977.3298	•	.08604	797.865	.98	0.9693	1.1618
0.027493 0.147265 711.164 1107.807 0.8966 10 0.02442 0.14857 669-416 1124.447 0.8975 0.02442 0.18857 669-416 1124.447 0.8875 0.02478 0.02478 0.18877 669-416 1124.447 0.8879 0.022481 0.218942 650.032 1149.472 0.8879 0.022481 0.218942 650.032 1149.472 0.8879 0.022481 0.22349 0.227032 0.424712 0.4479 0.4879 0.022349 0.227032 0.424712 0.4479 0.4879 0.022349 0.22248 0.237992 580.970 1100.647 0.77801	748.8848	•	0708	762.559	2	0.9398	1.2003
0.026479 0.118726 711.164 1107.007 0.8953 10.026479 0.18726 699.416 1138.001 0.8959 10.026479 0.21834 0.119346 669.164 1138.001 0.8959 10.022834 0.219342 669.164 1138.001 0.8959 10.022834 0.219342 669.164 1138.001 0.8959 10.022834 0.228942 690.4262 1169.472 0.8859 0.228349 0.228942 0.228942 1169.891 0.7959 10.022349 0.228942 0.239992 580.970 1100.647 0.7800 10.022146 0.339992 580.970 1100.647 0.7800 10.022146 0.339992 580.970 1100.647 0.7800 10.022146 0.339992 580.970 1100.647 0.7800 10.022149 0.433747 589.970 1100.647 0.77800 10.022149 0.433747 585.034 1166.107 0.77800 10.022149 0.433747 585.034 1166.107 0.77800 10.022149 0.433747 585.034 1166.107 0.77800 10.022149 0.433747 585.034 1166.107 0.77800 10.022149 0.433747 585.034 1166.107 0.77800 10.022149 0.433747 585.034 1166.107 0.7800 10.022149 0.433747 585.034 1166.107 0.7800 10.022149 0.433747 585.034 1166.107 0.7800 10.022149 0.433747 585.034 1166.107 0.7800 10.022149 0.433747 585.034 1166.107 0.7800 10.022149 0.433747 585.034 1166.107 0.5800 10.022149 0.021893 0.93524 435.039 11203.554 0.6471 10.03376 0.2349 1100.4827 0.021893 0.93524 435.039 1100.299 1100.492 0.03189 0.93524 0.01893 0.93624 0.021893 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.93624 0.021893 0.021893 0.93624 0.021893 0.93624 0.021893 0.021893 0.93624 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.021893 0.0218	535.6538	•	2698	735.075	3		1.2282
0.024781 0.218942 669.416 1134.347 0.68775 11 0.024781 0.218942 650.032 1149.472 0.88590 11 0.022349 0.227212 630.032 1199.216 0.81267 1105.216 0.22724 0.227212 614.268 1167.551 0.8108 1105.216 0.22724 0.22722 1107.551 1107.551 0.71809 0.22724	336.5323			711.164	8	96	1.2510
0.022354 0.191948 665,164 1136,472 0.64599 0.024781 0.225712 631.787 1155,216 0.6257 0.6257 0.022549 0.222354 0.222312 631.787 1155,216 0.6257 0.022354 0.222354 0.222354 0.222354 0.222354 0.222354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232354 0.232344 0.23234 0.23	150.5294	٠	-	914.689	1124.347	7	10.2.1
0.024126 0.24212 655.043 1194.472 0.68540 0.024126 0.024126 0.024126 0.022412 0.022412 0.022412 0.022412 0.022412 0.022412 0.022242 0.022242 0.022242 0.022242 0.022242 0.022242 0.022242 0.022242 0.022242 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022244 0.022242 0.022107 0.042247 0.042247 0.022242 0.02224 0.04224 0.02224 0.02224 0.04224 0.02224 0.02224 0.04224 0.02224	976.7792	.02553	0.191348		1138.001	0.8399	1.2854
0.022549 0.242712 631.787 1159.216 0.81267 0.022333 0.240307 591.258 1167.551 0.012303 0.22268 0.232949 591.258 1167.551 0.012268 0.232949 0.22268 0.239992 591.259 1186.107 0.7509 0.022268 0.239992 591.259 1186.107 0.7501 0.7501 0.022268 0.232447 594.493 1196.289 0.7501 0.7501 0.022246 0.22246 0.232477 594.493 1196.289 0.7501 0.7207 0.0221075 0.522840 519.422 1197.220 0.7207 0.0221075 0.522840 519.422 1197.220 0.7207 0.0221075 0.522840 519.422 1197.220 0.7207 0.0221075 0.522840 519.422 1197.220 0.6411 0.022017 0.022018 0.741119 46.237 1203.254 0.641119 0.022110 0.022110 0.022110 0.022218 0.241119 46.237 1203.254 0.641119 0.022110 0.022218 0.2524 448.627 1203.254 0.641119 0.2524 0.021119	814.5024	٠	0.215942	_	1149.472	0.48.0	1.3040
0.022549 0.272032 614.268 1167.251 0.7933 10.022548 0.27203 614.268 1167.251 0.7933 0.022548 0.272548 0.237992 580.970 1180.847 0.7809 0.022548 0.237992 580.970 1180.847 0.7809 0.7501 0.0227759 0.227759 0.227849 0.7271 0.72809 0.7271 0.0221075 0.252840 0.252840 1190.587 0.7277 0.590820 519.422 1197.520 0.7277 0.7201 0.020218 0.728173 519.422 1197.520 0.7277 0.720218 0.728173 590.4817 1200.088 0.7201 0.020218 0.728173 590.460 1200.254 0.6451 0.020218 0.937524 446.523 1200.854 0.6451 0.020218 0.937524 446.523 1200.854 0.6451 0.020218 0.937524 446.523 1200.854 0.6451 0.020218 0.937524 446.523 1200.854 0.6451 0.020218 0.937524 1.740390 1.750378 490.460 1200.854 0.6451 0.020218 0.52744 1.740390 1.750378 1.750378 1.750378 0.5544 0.020218 0.021793 1.750378 1.7504 1.750378 1.7504 1.7504 1.7504 0.021793 1.750778 1.75078	662.9961	٠	0.242712	631.787	1159.216	0.8267	1.3196
0.02233 0.304307 597358 1174,705 0.7953 0.0022146 0.37953 0.304307 5975358 1174,705 0.77953 0.7022146 0.379627 565.034 1186,107 0.7809 0.022105 0.422474 594.493 1190,589 0.77001 0.77501 0.0221075 0.522460 519,4817 1200,288 0.77007 0.7501 0.77007 0.0221075 0.522460 519,4817 1200,288 0.77007 0.77007 0.022107 0.50480 1.200,288 0.6481743 446,627 1203,595 0.6481 0.020218 0.93524 446,627 1203,595 0.6481 0.020218 0.93524 446,627 1203,595 0.6481 0.020218 0.93524 446,627 1205,395 0.6481 0.020218 0.93526 446,627 1205,395 0.6481 0.020218 0.93526 446,627 1205,395 0.6481 0.020218 0.93526 446,627 1205,395 0.6481 0.020218 0.93526 446,627 1205,395 0.6481 0.020218 0.93526 421,580 1205,395 0.6481 0.020218 0.93526 421,580 1205,395 0.6481 0.020218 0.93526 421,580 1205,395 0.6481 0.020218 0.93526 421,580 1205,395 0.6481 0.020218 0.93526 421,580 1202,206 0.6481 0.020218 0.93526 421,580 1202,206 0.6481 0.020218 0.93526 421,580 1202,206 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.93526 0.020218 0.020218 0.93526 0.020218	521.6270	0.023549	0.272032	614.268	1167.551	0.8108	1.3337
0.022568 0.339992 586,034 1180,847 0.7800 0.022568 0.473103 554,432 1190,589 0.7701 0.7501 0.0221759 0.473113 549,432 1190,589 0.7701 0.0221759 0.473113 549,432 1190,589 0.7701 0.022175 0.559680 519,422 1197,520 0.7701 0.022045 0.561229 490,460 1202.120 0.7701 0.022045 0.661229 490,460 1202.120 0.65129 0.7701 0.022045 0.661229 490,460 1202.120 0.6626 0.022045 0.661229 490,460 1202.220 0.6526 0.6315 0.022045 0.66129 0.66129 0.022045 0.6526 0.6315 0.022045 0.021959 0.65129 0.022045 0.021959 0.6526 0.6315 0.021959 0.023766 435,032 1203,595 0.6526 0.6319 0.021991 0.52992 395,068 1203,595 0.65189 0.65189 0.021893 381,984 1202,738 0.5546 0.021893 1.52922 395,068 1203,595 0.65992 0.018910 1.528922 395,068 1203,595 0.5599 0.018910 1.528922 395,068 1203,595 0.5599 0.018910 1.528922 395,068 1203,595 0.5599 0.018910 1.528922 395,068 1199,379 0.5546 0.0599 0.018910 1.528922 395,068 1199,379 0.5599 0.0599 0.018910 1.528922 395,068 1199,379 0.5546 0.018910 1.528922 395,068 1199,379 0.5546 0.018910 0.018910 1.528922 395,069 1199,379 0.5546 0.018910 0.018910 1.52892 395,069 1199,379 0.5546 0.018910 0.018910 1.52892 0.05992 0.018910 0.0	389.8149	0.023033	0.304307	597.358	Ξ.	0.7953	1.3472
0.022146 0.379407 565.034 1186.107 0.7850 10 0.0221759 0.423747 549.443 1190.589 0.7501 0.0221759 0.423747 549.443 1190.589 0.7501 0.0221075 0.528460 519.422 1197.520 0.77207 0.0221075 0.528460 519.4817 1200.088 0.77207 0.022108 0.641229 490.460 1202.120 0.7801 0.02218 0.741019 476.323 1203.654 0.77207 0.020218 0.741019 476.323 1203.654 0.6571 0.020218 0.741019 476.323 1203.654 0.6571 0.020218 0.93524 446.27 1205.395 0.6681 0.019732 0.93524 446.27 1205.395 0.6681 0.019710 1.059725 421.580 1205.395 0.6681 0.019710 1.347035 408.263 1204.850 0.6682 0.019710 1.347035 408.263 1204.850 0.6682 0.019710 1.347035 408.263 1203.395 0.5594 0.019710 1.347035 408.263 1201.206 0.5594 0.019710 1.347035 408.263 1107.275 0.5594 0.019710 1.347035 317.946 1107.275 0.5594 0.019710 1.347031 356.114 1199.379 0.5402 0.019710 1.347031 36.279 11189.462 0.4829 0.017710 1.347031 36.279 11189.462 0.4829 0.017710 1.347031 2.017704 1177.322 0.4829 0.017710 1.347031 2.017704 1177.322 0.4829 0.017710 1.347031 2.017704 1177.322 0.4829 0.017710 1.347031 2.017704 1177.322 0.0429 0.017710 1.347031 2.017704 1.0017704 1.377040 1.0170.322 0.017704 1.377040 1.0170.322 0.017704 1.377040 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704 1.0170.322 0.017704 0.01677 2.017704	267.0315	0.022568	0.339992	580.970	=	0.7800	1.3601
0.021759 0.423747 549,493 1190,589 0.7501 0.021404 0.528480 554,493 1194,589 0.7501 0.021404 0.528480 554,493 1194,581 0.7701 0.020770 0.59820 504,461 1200,088 0.7701 0.020770 0.59820 504,4817 1200,088 0.7701 0.02048 0.831743 446,627 1200,554 0.6516 1.0201968 0.831743 446,627 1205,389 1.020,6426 0.6516 1.0201968 0.831743 446,627 1205,380 0.6516 1.0201973 0.932724 448,627 1205,380 0.6516 1.0201973 1.103768 435,638 1204,850 0.6416 1.0201973 1.103768 435,638 1205,395 0.6416 1.0201973 1.103725 1.103726 435,603 1205,395 0.6416 1.0201973 1.103729	152,7839	0.022146	m	3	2	0.7650	1.3726
0.021404 0.528460 594.303 1194.371 0.7253 10 0.020770 0.528460 504.817 1200.088 0.7207 0.59088 0.661229 496.460 1202.120 0.66916 10.020770 0.59088 0.661229 496.460 1202.120 0.66916 10.020218 0.741013 476.323 1203.354 0.6771 1200.088 0.741013 476.323 1203.354 0.66771 1200.088 0.741013 476.323 1205.350 0.6681 10.05136 0.019312 1.053536 448.627 1205.350 0.6681 10.05136 1.063754 448.627 1205.350 0.66189 11.05136 42.243 1205.350 0.66189 11.05136 42.243 1205.350 0.66189 11.05136 42.243 1205.350 0.66189 11.05136 42.243 1205.350 0.66189 11.05136 11.05136 42.243 1205.350 0.66189 11.05136 11.05136 42.243 1205.370 0.51895 0.51895 11.05136 12.05.397 0.51895 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.05189 11.05136 12.0518 11.0518 11.05136 12.0518 11.0	046.6161	0.021759		549.493	190.58	0.7501	1.3848
0.021075 0.528480 519,422 1197,520 0.7207 0.5002048 0.65711 0.002048 0.651229 490,460 1202.020 0.70011 0.657129 60.65229 490,460 1202.020 0.70011 0.657129 60.65229 490,460 1202.020 0.60524 0.65711 0.0019968 0.651324 448,627 1203,654 0.65711 0.0019968 0.831374 462,385 1204,895 0.6935 0.019312 0.93374 448,627 1205,392 0.61899 0.019310 1.347035 468,627 1205,392 0.61899 0.019310 1.347035 408,263 1204,895 0.61899 0.019310 1.347035 408,263 1204,895 0.61899 0.019310 1.347035 408,263 1204,895 0.6042 0.01939 1.328922 395,003 1204,895 0.5395 0.01893 1.747035 408,263 1204,895 0.5395 0.01893 1.747035 408,263 1204,895 0.5395 0.01893 1.747035 408,203 1197,275 0.5597 0.01893 1.747035 408,203 1197,275 0.5597 0.01893 1.747035 408,595 1194,910 0.5140 0.01893 1.747035 408,595 11107,275 0.5446 0.01893 1.747035 1.747035 1.747035 1.747035 0.44710 0.01893 1.747035 1.74	948.0988	0.021404	0.473103	534.303	1194.371	0.7353	1.3967
0.020770 0.590820 504.817 1200.088 0.7061 0.02028 0.661229 496.460 1202.120 0.6916 0.02028 0.741013 476.323 1203.654 0.66126 0.019518 0.741014 476.323 1204.721 0.6626 0.019519 1.053524 448.627 1205.350 0.66189 0.019510 1.053724 426.627 1205.350 0.6189 0.019510 1.294735 408.263 1205.392 0.6189 0.019529 1.189955 421.860 1205.392 0.6189 0.019520 1.294729 1.294729 1.294729 0.6189 0.018729 1.740390 36.114 1199.375 0.5189 0.01873 2.27681 36.114 1199.375 0.5189 0.01873 2.617991 34.333 1194.910 0.5489 0.01874 2.617991 34.333 1194.910 0.5489 0.01874 4.077606 305.370 1186.429 0.5489	856.8275	0.021075	-	519.422	1197.520	0.7207	1.4084
0.022485	772.4185	0.020770	n	504.817	200.08	0.7061	•
0.020218 0.741019 476.323 1223.654 0.6426 0.019328 0.938274 462.627 1.06481 0.6461 0.019329 1.189955 462.627 1205.356 0.6426 0.019310 1.053768 425.030 1205.356 0.6489 0.019310 1.347039 406.263 1205.356 0.6489 0.019100 1.347035 406.263 1203.959 0.6489 0.018579 1.740390 381.984 1203.959 0.6489 0.018579 1.740390 381.984 1201.206.859 0.5895 0.018579 1.740390 381.984 1201.206 0.5895 0.018579 1.740390 381.984 1202.278 0.5895 0.01857 2.21841 356.114 1199.379 0.5895 0.01867 2.276841 356.114 1199.379 0.5824 0.01867 3.502843 317.946 1197.375 0.5824 0.01767 4.76566 305.376 1188.462 0.5824	694.5060	0.020485	-0	490.460	202-12	0.6916	_
0.019968 0.831743 462.385 1204.721 0.6626 0.01999 0.01912 0.932254 448.627 1205.350 0.6481 0.019110 1.347035 421.580 1205.392 0.6189 0.019110 1.347035 421.580 1205.392 0.6189 0.019110 1.347035 408.263 1206.850 0.66481 0.019110 1.347035 408.263 1206.850 0.6189 0.018120 1.528922 395.068 1203.392 0.5189 0.01892 0.01893 1.74039 395.068 1203.738 0.5597 0.01893 2.278841 356.114 1197.275 0.5597 0.01833 2.278841 356.114 1197.275 0.5597 0.018087 3.021893 330.592 1194.910 0.546 0.018087 3.021893 330.592 1194.910 0.546 0.017808 4.077604 305.370 1189.462 0.546 0.017808 4.077604 305.370 1189.462 0.54829 0.017852 5.607041 280.409 1189.154 0.4621 0.4985 0.017817 7.87781 255.674 1176.098 0.4186 0.4186 0.01781 2.56582 1182.322 0.4184 0.4186 0.3184 0.01781 1.342943 232.1381 1176.322 0.3334 0.016499 1.37566582 1182.322 0.3334 0.016499 0.16482 1182.322 0.2792 0.016499 0.16482 1182.322 0.2792 0.016499 0.16482 1182.322 0.2792 0.016499 0.16650 32.151173 1170.422 1146.858 0.2024 0.016499 0.16642 0.016499 0.16642 0.016499 0.16642 0.016499 0.16642 0.016499	622,7381	0.020218	^	476.323	203.65	0.6771	1.4426
0.019732 0.935254 448.627 1205.350 0.6481 0.019792 0.017792 0.0177		0.019968	83174	462.385	204.72	0.6626	1.4539
0.019510 1.053768 435.030 1205.566 0.6335 0.019299 1.189955 422.580 1205.392 0.6189 0.019100 1.528922 395.068 1203.959 0.51899 0.019100 1.528922 395.068 1203.959 0.51899 0.018727 1.528922 395.068 1203.959 0.51899 0.018527 1.528922 395.068 1203.959 0.51899 0.018537 1.528922 395.068 1203.959 0.51899 0.018237 2.617991 345.313 1197.275 0.5294 0.018037 2.617991 345.313 1197.275 0.5294 0.018037 2.617991 345.313 1197.275 0.5294 0.018037 2.617991 345.313 1197.275 0.5294 0.017044 4.077606 305.370 1189.462 0.4829 0.017677 4.769533 2.92.859 1186.408 0.4671 0.017677 4.769533 2.92.859 1186.408 0.4671 0.017722 2.6.677141 2.68.015 1179.713 0.4935 0.6421 0.017728 0.6777881 2.66.774 1176.098 0.4184 0.017728 0.017728 2.6.6771481 2.66.774 1176.098 0.4184 0.017728 0.017728 1.342943 2.31.132 1160.132 0.3394 0.016732 2.6.65282 182.202 1162.232 0.2595 0.3394 0.016499 51.966376 146.321 1157.312 0.2505 0.016499 51.966376 146.321 1137.313 0.2505 0.016499 51.966376 146.321 1137.313 0.2605 0.016499 51.966376 146.321 1137.314 0.182.820 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.1609 0.01649 0.016499 51.956376 1102.295 11127.895 0.01649 0.01649 0.016499 51.969376 120.299 1102.608 0.01649 0.	3	0.019712		448.627		0.6481	1.4652
0.019299 1.189955 421.580 1205.392 0.6189 0.019100 1.347035 401.263 1205.392 0.6042 0.018910 1.528922 395.068 1203.959 0.5895 0.018912 1.740390 381.984 1202.795 0.5895 0.5895 0.01892 1.740390 381.984 1202.795 0.5895 0.5895 0.018957 1.987291 365.114 1199.379 0.5597 0.018393 2.277841 356.114 1199.379 0.5597 0.018393 2.277841 356.114 1199.379 0.5597 0.018393 2.027864 1305.313 1197.275 0.5597 0.01892 0.01794 3.502843 330.592 1194.310 0.5846 0.01794 3.502843 330.592 1194.310 0.5846 0.01794 3.502843 330.592 1194.310 0.5846 0.017804 3.502843 330.592 1189.462 0.5846 0.017804 3.502843 330.592 1189.462 0.5846 0.017817 7.877881 255.674 1175.098 0.4671 0.01783 2.24859 1186.395 0.4671 0.01783 2.54288 18.25.674 1176.098 0.3394 0.018618 20.673408 20.673408 16.7534 1164.328 0.3599 0.01673 25.665288 182.505 1164.328 0.3599 0.01673 25.665288 182.505 1164.328 0.2576 0.016499 51.966376 146.321 1132.722 0.2605 0.016499 51.966376 146.321 1132.722 0.2605 0.016499 67.16644 122.290 1127.852 0.221 0.016499 51.966376 120.299 1127.852 0.221 0.016499 51.966376 120.299 1127.859 0.01673 0.01649 51.966376 120.299 1127.859 0.01673 0.01649 51.966376 120.299 1127.859 0.01649 0.016499 51.966376 120.299 1127.859 0.01649 0.016499 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 51.966376 120.299 1127.859 0.01649 0.01649 0.01649 51.966376 0.01649 51.000000000000000000000000000000000000	440 0850	0.010510		435.030	1205.566	0.6335	1.4765
0.019100 1.347035 406.263 1204.850 0.6642 0.018910 1.528922 399.068 1203.959 0.5895 0.018910 1.528922 399.068 1202.738 0.55895 0.018933 2.276841 356.014 1199.379 0.5594 0.018393 2.276841 356.114 1199.379 0.5594 0.018237 2.676841 356.114 1199.379 0.5594 0.018237 2.677891 336.969 1194.910 0.5946 0.018237 2.67893 317.946 1192.301 0.4985 0.5140 0.017808 4.077606 395.370 1189.462 0.4829 0.017808 4.077606 395.370 1189.462 0.4829 0.017877 4.769533 3292.869 1189.462 0.4829 0.017877 4.769533 295.869 1189.462 0.4829 0.017877 4.769533 255.674 1176.098 0.4985 0.017808 9.427140 268.015 1172.322 0.4985 0.017808 0.017808 11.78278 254.341 1176.098 0.4518 0.04349 0.017808 11.78278 254.341 1176.098 0.4518 0.2792 0.016872 25.665288 182.505 1156.328 0.2792 0.016872 25.665289 182.505 1157.312 0.2792 0.2792 0.016872 25.665289 1182.202 1157.518 0.2792 0.016872 25.665289 1182.202 1157.212 0.2792 0.016872 25.665289 1182.202 1157.212 0.2792 0.016872 25.665289 1182.202 1157.212 0.2792 0.016872 25.665289 1182.202 1157.212 0.2792 0.016872 25.665289 1102.299 1122.913 0.02024 0.016192 293.189777 746.201 1177.914 0.18228 0.01697 0.016192 293.189777 746.394 1107.2698 0.01697 0.016192 293.189777 746.394 1107.2698 0.01697 0.01697 0.016972 256.414 1008.967 0.0022 25.414 1008.967 0.01692 256.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.977 74.395 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.977 25.6444 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.414 1008.967 0.0022 25.214 1008.977 0.0022 25.414 1008.967 0.0022 25.214 1008.977 0.0022 25.414 1008.9	300 6324	0101010	7	421.580	1205.392	0.6189	1.4878
0.018970 1.528922 395.068 1203.959 0.5895 0.018729 1.740390 381.984 1202.738 0.55746 0.018729 1.740390 381.984 1202.738 0.55746 0.01837 2.617991 356.114 1199.379 0.5597 0.01837 2.617991 356.114 1199.379 0.5597 0.01837 2.617991 356.114 1199.379 0.5597 0.018087 3.021893 330.592 1194.910 0.5140 0.018087 3.021893 330.592 1194.910 0.5140 0.018087 3.021893 330.592 1194.910 0.5140 0.018087 4.769533 292.859 1189.462 0.4629 0.017808 6.627140 258.019 1183.154 0.4511 0.017832 5.607041 258.049 1183.154 0.4511 0.017832 6.627140 258.019 1176.098 0.46711 0.017832 6.627140 258.019 1176.098 0.46711 0.017004 13.75040 255.674 1176.098 0.46711 0.017004 13.75040 255.674 1176.098 0.3852 0.3859 0.01690 16.793768 206.733 1160.132 0.3859 0.2776 0.016499 16.793768 126.292 1160.132 0.2276 0.016499 51.966376 1194.223 1160.132 0.2276 0.016499 51.966376 1146.321 1137.914 0.182.89 0.2792 0.016499 51.966376 1162.290 1127.852 0.2221 0.016499 51.966376 1162.290 1127.852 0.2221 0.016499 51.966376 1162.290 1127.852 0.2221 0.016499 51.966376 1162.290 1127.852 0.016499 0.016499 51.96647 122.290 1127.852 0.016499 0.016499 51.96647 0.00299 1107.755 0.016499 0.016499 51.966376 1162.290 1122.859 0.01699 0.016499 51.96647 122.290 1127.859 0.016499 0.016499 51.96647 122.290 1127.852 0.016499 0.016499 51.96647 122.290 1127.852 0.016499 0.016499 51.96647 0.002.893 1107.293 0.016499 0.016499 51.96647 0.002.893 1107.2899 0.016499 0.016499 51.96647 0.002.893 1107.2899 0.016499 0.016499 51.96647 0.002.893 1107.2899 0.016499 0.016499 0.016499 51.96647 0.002.893 1107.2899 0.016499 0.01	246.046	0.019299	•	408 243	1204.850	0.6042	1.4992
0.018357 1.987291 363.002 1201.206 0.5546 0.018393 2.276841 356.114 1199.379 0.5546 0.018393 2.276841 356.114 1199.379 0.5546 0.018393 2.276841 356.114 1199.379 0.5546 0.01837 2.617891 330.592 1194.910 0.5140 0.018087 3.021893 330.592 1194.910 0.5140 0.017808 4.077606 395.370 1189.462 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 4.769533 292.869 1186.408 0.4629 0.017877 7.877881 255.674 1176.098 0.4511 0.4949 0.017808 0.42243 231.132.132 1168.395 0.3682 0.017808 11.342943 231.132.132 1168.395 0.3682 0.01890 0.01891 0.793768 206.753 1166.328 0.2862 0.01891 0.01892	2440.440	0.00.00	•	100 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	12040	4000	5104
0.018557 1.780590 350.002 1201.206 0.5597 0.018587 1.992671 1999.379 0.5597 0.018587 1.992671 1999.379 0.5597 0.018587 2.276841 350.1194 1199.379 0.55294 0.018237 2.617991 350.1194 1199.379 0.55294 0.018237 2.617991 350.592 1194.910 0.51949 0.5101000000000000000000000000000000000	303.0349	016810		390.086	203.43	0.3043	1.0100
0.018393 2.276841 356.102 1199.379 0.55446 0.018237 2.617991 343.313 1197.275 0.5294 0.018237 2.617991 343.313 1197.275 0.5294 0.018237 2.617991 343.313 1197.275 0.5294 0.018237 0.017064 3.5021893 330.592 1197.275 0.5140 0.017064 4.077606 305.370 1189.462 0.4671 0.4929 0.017552 5.607041 2280.4699 1189.713 0.4671 0.4186 0.017337 7.877881 255.674 1176.098 0.4186 0.4186 0.01717 7.877881 255.674 1176.098 0.4186 0.4186 0.01717 7.877881 255.674 1176.098 0.4186 0.4186 0.01717 7.877881 255.674 1176.395 0.3852 0.016908 16.793768 206.753 1160.132 0.3652 0.016908 16.793768 194.614 1155.816 0.3599 0.2792 0.016672 40.66582 1152.293 1160.132 0.2792 0.016672 40.66582 1152.293 1127.815 0.2202 0.201649 51.966376 116.295 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 51.966376 1127.815 0.2024 0.01649 62.3039 0.01652 1127.815 0.01639 0.01638 87.76644 1122.293 1107.755 0.1699 0.01652 127.33508 62.394 1107.755 0.01659 0.01659 0.01659 0.01659 88.33508 0.01652 127.92623 26.414 1098.967 0.01652 127.92623 26.414 1098.967 0.00288 0.0076 0.016022 1276.9377 14.377 1091.705 0.00288	265.4243	0.018729		106-106	1201 204	70.00	1.5240
0.018237 2.617991 343.313 1197.275 0.5294 10.018037 3.02594 330.592 1194.910 0.5140 0.5140 0.018087 3.02594 317.946 1197.301 0.6985 10.01808 4.077606 305.370 1189.462 0.64629 0.601770 4.76953 292.859 1186.408 0.4671 0.017717 4.769533 292.859 1186.408 0.64571 0.017717 7.877881 258.015 1172.713 0.4939 0.01720 0.01720 9.422140 258.015 1172.713 0.4939 0.01720 0.01720 9.422140 258.015 1172.322 0.4020 0.01720 0.01720 0.42943 234.381 1172.322 0.4020 0.01720 0.01720 0.4020 0.01720 0.01720 0.4020 0.01720 0.01720 0.4020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.01720 0.01720 0.2020 0.017	7640167	0.018357	147/041	307.000	: 8	4444	1 5660
0.011007	201-102	645910-0	1.500/7.7	920-119	, ,	6.040	•
0.017944 3.502543 317.946 1192.301 0.4929 0.017944 4.077606 305.370 1189.462 0.4629 0.017808 4.077606 305.370 1189.462 0.4629 0.017877 4.769533 292.859 1186.408 0.4671 0.017872 5.607041 2280.409 1183.154 0.4571 0.4020 0.01782 5.607741 2280.409 1183.154 0.4571 0.4939 0.01782 6.627740 258.049 1179.713 0.4349 0.017703 113.342943 233.132 1166.132 0.3652 0.016808 16.793768 20.6.753 1166.328 0.3652 0.017004 13.750690 218.924 1165.328 0.3652 0.016808 16.793768 20.6.753 1160.132 0.3939 0.016872 25.66528 1186.309 0.3156 0.016872 40.66582 1186.321 1137.518 0.2203 0.016872 40.66582 1186.321 1137.518 0.2203 0.01689 51.966376 1166.321 1137.518 0.2203 0.01689 0.01689 51.966376 1166.321 1137.518 0.2203 0.01689 0.01689 115.38731 110.2993 0.1823 0.01689 0.01689 155.87390 86.3394 1107.755 0.01689	173.9342	0.018237	2.61/991	343.513	7 6	, ,	102201
2.248 0.017944 3.502543 317.940 1195.501 0.4829 2.257 0.017808 4.077606 305.370 1189.462 0.4671 2.969 0.01767 4.769533 292.859 1186.402 0.4511 2.969 0.017672 4.769533 292.859 1186.402 0.4511 3.3122 0.017731 7.87788 255.674 1176.098 0.4186 3.393 0.017204 13.750690 218.924 1166.395 0.4186 2.247 0.017004 13.750690 218.924 1166.328 0.3652 2.247 0.016918 20.673405 1166.328 0.3652 2.247 0.016618 20.65582 1166.328 0.3652 2.247 0.016690 16.79376 170.422 1166.328 0.3156 2.995 0.016690 12.15173 170.422 1146.858 0.276 2.996 0.016690 22.15173 170.422 1146.858 0.2221 2.918 0.016690	149-7103	0.018087	3.021893	360.056	16.6	•	1.50.00
2527 0.017808 4.07606 505.370 1185.492 0.4671 1786.092 0.017808 4.076953 292.859 1186.408 0.4571 0.45786 0.017852 5.60741 280.409 1186.408 0.4511 178.312 0.017432 6.627140 268.015 1172.312 0.4349 0.4186 0.01731 7.877881 255.674 1172.098 0.4186 0.4186 0.01703 11.342543 231.312 1172.322 0.4020 0.01703 11.342643 231.312 1166.328 0.3852 0.942 0.016908 16.793768 206.753 1160.132 0.3593 0.3593 0.016908 16.793768 206.753 1160.132 0.3593 0.3593 0.016908 16.793768 206.753 1160.132 0.3593 0.3593 0.016650 32.151173 170.422 1146.858 0.2976 0.3334 0.016490 32.151173 170.422 1146.858 0.2976 0.2978 0.016490 0.016490 0.165228 1158.362 1132.232 0.2792 0.2221 0.016490 0	128.2248	0.017944	٠	317.946	106.2611	•	1.0000
9969 0.017552 5.607041 280.409 1183.154 0.4511 9969 0.017552 5.607140 268.0409 1179.713 0.4349 3393 0.017317 7.877881 255.674 1176.098 0.4186 9030 0.017208 9.422158 243.381 1172.322 0.4020 993 0.017703 11.342943 231.31 1166.395 0.486 994 0.017704 13.742943 231.31 1166.395 0.4020 995 0.017704 13.742943 231.31 1166.328 0.4020 1995 0.016918 16.793768 206.753 1166.328 0.3569 1995 0.016918 16.793768 206.753 1166.328 0.3569 1995 0.016670 32.15173 170.422 1146.328 0.2792 118 0.016499 51.965376 146.321 1132.232 0.2792 137 0.016499 51.966376 166.325 1146.328 0.2792 149	109.2527	0.017808		305-370	9 9	•	1007
9969 0-017552 5-607041 280-409 1183-129 0-4349 13122 0-017432 6-627140 268-019 1187-129 0-4349 13122 0-017432 6-627140 268-019 1187-129 0-4186 1393 0-017208 9-422158 243-381 1176-098 0-4186 0-4020 1393 0-017208 9-422158 218-132 1166-132 0-4020 14942 0-017208 13-75090 218-9942 1166-139 0-3652 13-751 0-016908 16-793768 206-753 1166-132 0-3652 13-393 0-016908 16-793768 206-753 1160-132 0-3652 13-393 0-016650 32-151173 170-614 1155-816 0-3594 1-2247 0-016650 32-151173 170-624 1166-858 0-2792 1187-818 0-2792 1-245 1187-818 0-2792 1-245 1187-818 0-26582 1187-818 0-26		0.017677	.76953	292.859	2 :	•	1.0091
3122 0.017432 6.627140 268-012 1179-113 0-5347 3939 0.017208 9.422158 255.674 1176.028 0.4186 8939 0.017208 9.422158 255.674 1176.028 0.4020 89942 0.017004 13.750690 218.924 1166.328 0.3652 3995 0.016908 10.793768 206.753 1166.132 0.3509 3995 0.016673 22.665288 182.505 1151.389 0.3154 3995 0.016673 25.665288 182.505 1151.389 0.3154 3995 0.016672 25.665288 182.505 1151.389 0.3154 3995 0.016672 25.665288 182.505 1151.389 0.2792 4118 0.016672 32.151173 170.422 1146.858 0.2274 3997 0.016672 67.140421 134.298 1137.722 0.2274 3997 0.016365 87.768644 122.290 1127.852 0.2024 3996 0.01639 155.87030 98.311 1117.914 0.1823 3475 0.016198 212.138521 86.335 1112.859 0.1409 3794 0.016112 411.935085 62.394 1107.755 0.1409 3794 0.01612 411.935085 62.394 1107.755 0.1409 3794 0.01612 411.935085 62.394 1107.755 0.00528 3842 0.01602 1276.922623 26.414 1086.967 0.0528		0-017552	1+0/09.5	260-409	461-6811	•	1.023
3993 0.017317 7.877881 255.674 1176.079 0.4020 99030 0.017208 9.422158 243.881 1172.322 0.4020 99042 0.017004 13.750690 218.924 1164.328 0.3652 19942 0.017004 13.750690 218.924 1164.328 0.3652 12247 0.016908 16.793768 206.753 1160.132 0.3509 10.016732 25.655288 182.8016 0.3334 10.016572 25.655288 182.802 1151.399 0.2976 10.016572 25.655288 170.422 1146.858 0.2976 10.016572 40.655682 158.362 1146.858 0.2976 10.016499 0.016572 40.65682 158.362 1142.852 0.2272 1397 0.016499 116.182228 110.295 1122.913 0.2024 146.9 0.01612 411.935085 62.394 1102.608 0.1195 146.9 0.01612 411.935085 62.394 1107.755 0.1195 134.2 0.016071 858.22623 26.414 1086.967 0.0523 136.1 0.016072 1276.922623 26.414 1086.967 0.0528		0.017432	6.627140	20802	61/9-113	•	1.03/0
9930 0.017208 9.422158 243.391 1176.322 0.3952 0.3953 0.017103 11.342943 231.312 1166.395 0.3952 0.3953 0.017103 11.342943 231.312 1166.395 0.3952 0.3953 0.017004 13.75049 206.753 1160.132 0.3569 0.3599 0.316818 20.673405 194.614 1155.386 0.3599 0.3334 0.016818 20.673405 194.614 1155.389 0.3334 0.3935 0.016872 32.65528 182.565 1165.389 0.2976 0.3334 0.01689 0.01689 11.966376 1146.321 1137.518 0.22792 0.2752 0.016499 51.966376 1146.321 1137.518 0.2209 0.2797 0.016499 51.966376 1166.329 1127.852 0.2221 0.201649 0.016365 116.18228 110.295 1122.913 0.2024 0.01636 116.18228 110.295 1122.913 0.2024 0.01639 0.01639 122.390 1127.852 0.31649 0.01639 0.01639 0.01639 0.01639 0.01639 0.01639 0.01639 0.01639 0.01639 0.01639 0.01632 293.189777 74.364 1107.755 0.1699 0.01615 293.189777 74.364 1107.424 0.01638 128.3228 0.01637 0.01632 1276.922623 26.414 10086.967 0.00528 0.01692 1276.922623 26.414 10086.967 0.00528 0.01692 1941.25668 14.377 10081.705 0.00288	54.3393	0.017317	7.877881	255-674	860.0711		6760-1
6.9942 0.017004 11.5424945 2.18.924 1166.379 0.3672 6.9942 0.0107004 13.750690 218.924 1166.132 0.3509 6.2247 0.016818 20.673405 194.614 1155.816 0.3594 9.3985 0.016872 22.5662288 182.505 1151.389 0.3156 2.0983 0.016672 32.151173 170.426 1146.858 0.2792 2.0983 0.016672 40.665682 158.362 1146.232 0.2792 2.0983 0.016672 40.665682 1134.298 1137.518 0.2792 7.247 0.016499 51.966376 146.321 1137.518 0.2265 7.247 0.016499 51.966376 1122.298 1122.291 0.2265 2.25094 0.016499 51.966376 116.2228 1102.295 1122.913 0.2024 2.25094 0.016349 115.182228 110.295 0.1623 0.1623 0.1623 2.250 0.016169 125.387039 98.311 <td>44.9030</td> <td>07/10</td> <td>961274.6</td> <td>106.642</td> <td>776 -7111</td> <td></td> <td>C10001</td>	44.9030	07/10	961274.6	106.642	776 -7111		C10001
4.2247 0.016478 13.73048 206.734 1160.132 0.3509 4.2247 0.016818 20.673405 194.614 1155.816 0.3334 9.3985 0.016630 22.673405 194.614 1155.816 0.3334 2.0983 0.016650 32.131173 170.422 1146.858 0.2776 2.0983 0.016450 32.131173 170.422 1146.858 0.2776 2.0983 0.016499 51.966376 146.22 1142.232 0.2772 7.257 0.016499 51.966376 112.298 112.722 0.2415 4.1397 0.016499 67.140421 134.296 112.722 0.2415 4.1397 0.016349 116.182228 110.295 1127.852 0.2221 1.647 0.016549 155.8703 86.335 1112.893 0.1653 1.647 0.016549 155.8703 86.334 1107.695 0.1409 1.1469 0.016549 116.18222 110.2608 0.1609 0.1609	0 1	601/10-0	"	761-167	1144 338	•	1 4004
2.2.47 0.016818 20.673405 194,614 1155,816 0.334 9.3985 0.016732 22.665288 182.504 1151,389 0.3156 2.0983 0.016650 32.151173 170,422 1146,858 0.2792 2.0983 0.016650 32.151173 170,422 1146,858 0.2792 9.4118 0.016572 40.65582 158.362 1146,858 0.2792 9.4118 0.016430 67.140421 134,232 1137,518 0.22792 9.5094 0.016430 67.140421 132.293 1127,852 0.2221 1.0699 0.01636 116,18228 110,295 1127,852 0.2221 1.144 0.01636 27,18977 74,364 1107,852 0.1609 0.794 0.01615 29,18977 74,364 1107,759 0.1409 0.794 0.01616 49,082329 50,417 1091,424 0.0976 0.794 0.01605 186,52202 26,414 1086,967 0.0528		*00/10-0	•	476-017	020-6011	•	1.7147
5.393 0.01673 25.66228 182.50 1151.389 0.3156 2.0983 0.01667 25.66528 182.50 1146.85 0.2976 2.0983 0.01667 25.66528 158.362 1146.85 0.2976 9.4118 0.01649 51.96637 146.321 1137.518 0.2792 5.5094 0.01649 67.144621 134.290 1127.722 0.2415 4.1397 0.01649 67.144621 134.290 1127.852 0.2213 3.0699 0.01636 87.766644 122.290 1127.852 0.2224 1.6174 0.01624 155.870390 89.311 1117.814 0.1622 1.146 0.01615 293.189777 74.364 1107.755 0.1608 0.7994 0.01617 411.935085 62.394 1107.424 0.0976 0.5472 0.01607 889.082329 38.427 1092.208 0.0753 0.2414 0.016022 1941.256668 14.377 1081.705 0.0288		9069TO-0	10.173.00	104 414	761-0011	•	1.7345
2.0983 0.016650 32.151173 170.5.907 1131.297 0.2976 2.0983 0.016650 32.151173 170.5.907 1131.297 0.2976 2.0983 0.016650 32.151173 170.5.907 1131.297 0.21650 0.2976 3.418 0.016490 51.966376 146.321 1131.518 0.2605 3.5094 0.016490 51.966376 126.298 1132.722 0.2415 3.0699 0.016365 87.766644 122.298 1132.512 0.2221 3.0699 0.016365 87.766644 122.299 1122.913 0.2024 3.2450 0.01636 155.870390 88.331 1117.8914 0.1823 1.1469 0.016152 293.189777 74.364 1107.755 0.1618 0.5472 0.016078 589.082329 50.417 1092.608 0.0195 0.3473 0.016078 889.522623 26.414 1086.967 0.05288 0.2414 0.016022 1941.256668 14.377 1091.705 0.02288	,,	010010-0	204619402	F10.441	0400000	;	7830
9.4118 0.016572 40.65682 158.232 1.42.232 0.2792 9.4118 0.016499 51.966376 146.321 1137.518 0.2605 7.2457 0.016499 51.966376 146.321 1137.518 0.2605 5.5094 0.016490 67.140421 134.298 1132.722 0.2415 4.1397 0.016465 87.766644 122.290 1127.852 0.2221 2.2450 0.016499 151.618228 110.2993 1122.913 0.2024 2.2450 0.01649 155.870390 98.313 1117.914 0.1823 1.51469 0.016152 293.189777 74.364 1107.755 0.1409 0.7994 0.016112 411.935085 62.394 1107.755 0.1195 0.5472 0.016078 885.522623 26.417 1097.424 0.05753 0.2414 0.016051 858.522623 26.414 1086.967 0.0528 0.1552 0.016022 1941.256668 14.377 1081.705 0.0288	•	767910-0	007000007	COC+701	100-1011	•	1774
0.016499 51.966376 146.321 1137.518 0.2605 0.016430 67.140421 134.298 1132.722 0.2415 0.016365 87.768644 122.290 1127.852 0.2421 0.016364 116.182228 110.295 1122.8913 0.2024 0.016198 212.138521 110.295 1122.8913 0.2024 0.016198 212.138521 86.335 1112.859 0.1609 0.01615 293.189777 74.364 1107.755 0.1609 0.016078 589.082329 50.417 1097.424 0.0976 0.016032 1276.922623 26.414 1086.967 0.0528 0.016022 1941.256668 14.377 1081.705 0.0288	v	0.0010-0	61777707	774 031	1142 222		1.7927
0.016430 67.140421 134.298 1127.722 0.221 1.8 0.016436 87.768644 122.290 1127.852 0.2221 1.8 0.01636 87.768644 122.290 1127.852 0.2221 1.8 0.01634 155.8528 110.295 1127.852 0.2024 1.8 0.016198 212.138521 86.335 1117.914 0.1823 1.9 0.01615 212.138777 74.364 1107.755 0.1609 1.9 0.01617 411.935085 62.394 1102.608 0.1195 1.9 0.016078 859.082329 50.417 1097.424 0.0976 2.0 0.016032 1276.922623 26.414 1086.967 0.0553 2.0 0.016022 1941.256668 14.377 1091.705 0.0288 2.1	0174.	7.6910.0	7000000	146 221	1127 610		1.8120
0.016365 87.766644 1322.290 1127.852 0.2221 1.8 0.016365 116.182228 110.295 1122.913 0.2024 1.8 0.016249 155.870390 98.311 1117.814 0.1823 1.9 0.016152 293.189777 74.364 1107.755 0.1618 1.9 0.016112 411.935085 62.394 1102.609 0.195 1.9 0.016078 589.082329 50.417 1097.208 0.0753 2.0 0.016032 1276.922623 26.414 1086.967 0.05288 2.0	747.	5 2	0/5004.15	776-047	1121 121		•
0.016304 116.18228 116.295 112.913 0.2024 1.8 0.016304 116.18228 116.295 112.913 0.2024 1.8 0.01649 155.870390 98.311 1117.914 0.1623 1.9 0.016192 293.189777 74.364 1107.755 0.1618 1.9 0.016112 411.935085 62.394 1107.755 0.1609 1.9 0.016071 859.082329 52.394 1107.424 0.0195 1.9 0.016051 858.522072 38.427 1097.424 0.0753 2.0 0.016022 1941.256668 14.377 1091.705 0.0288 2.1	•	56910	174041-10	067-661	1137.062	0.2221) «
0.016249 155.87030 100.016249 100.016249 155.87030 0.016249 1117.914 0.1623 1.99 0.016198 212.138521 86.335 1112.859 0.1618 1.99 0.016152 293.189777 74.364 1107.755 0.1409 1.99 0.016112 411.935085 62.394 1102.4608 0.01195 1.99 0.016051 858.522072 38.427 1097.424 0.0976 2.00 0.016051 858.522072 26.414 1086.967 0.0523 2.00 0.016022 1941.256668 14.377 1091.705 0.0288 2.1	161.6	10307	4400044	110 208	1122 012	0.2024	
0.016198 132.017370 76.351 1112.859 0.1618 1.99 0.016198 2.12.138521 86.335 1112.859 0.1618 1.99 0.016152 293.189777 74.364 1107.755 0.1409 1.99 0.016112 411.935085 62.394 1107.424 0.01976 2.00 0.016078 859.08232 50.417 11092.208 0.0753 2.00 0.016032 1276.922623 26.414 1086.967 0.05288 2.00 0.016022 1941.256668 14.377 1091.705 0.0288 2.1	6600°E	10000	077791-011	110.00	1117 914	1822	
0.016152 293.189777 74.364 1107.755 0.1609 1.99 0.016112 411.935085 62.394 1102.608 0.1195 1.99 0.016078 589.082329 50.417 1097.208 0.0976 2.0 0.016078 1898.52207 38.427 1092.208 0.0753 2.0 0.016032 1276.922623 26.414 1086.967 0.05288 2.1	0647.7	647910	065010-661	10.0	1117 680		٠ ٥
1969 0.016112 411.935085 62.394 1107.608 0.1195 1. 1794 0.016112 411.935085 62.394 1102.608 0.01195 1. 1577 0.016078 858.08232 36.417 1097.424 0.0976 2. 1587 0.016031 1276.922623 26.414 1086.967 0.0523 2. 1552 0.016022 1941.256668 14.377 1081.705 0.0288 2.	1.6174	861910	176861.512	•	600-7111	; -	٠.
.7994 0.016112 411.335085 62.394 1102.608 0.1175 1. .5472 0.0166018 589.082329 50.417 1097.424 0.0976 2. .5414 0.016603 1276.922623 26.414 1086.967 0.0523 2. .5414 0.016032 1276.922623 26.414 1086.967 0.0523 2. .1552 0.016022 1941.256668 14.377 1081.705 0.0288 2.	1.1469	016152	293.189777	900	667 - 2011	•	•
.5472 0.016078 589.082329 50.417 1097.424 0.0757 2. 2573 0.016051 858.52207 38.427 1098.208 0.0753 2. 25414 0.016032 1276.922623 26.414 1086.967 0.0523 2. 1552 0.016022 1941.256668 14.377 1081.705 0.0288 2.	0.7994	016112	411.935085	5	1102.608	0.1175	٠
.3673 0.016051 858.522072 38.427 1092.208 0.0753 2.063	0.5472	016078	589.082329	7	42	97 60 0	•
.2414 0.016032 1276.922623 26.414 1086.967 0.0253 2.039 .1552 0.016022 1941.256668 14.377 1081.705 0.0288 2.137	0.3673	016051	858.52207	8.42	ָ מַ	0.0753	500
-1552 0.016022 1941-256668 14.377 1081-705 0.0288 1.35	.241	016032	216.92262	٠.	9	6760.0)
	.155	ខុ	941.256	÷	1081.705	70.	151.

COMPARISON POINTS FOR ASME TABLE 3, REF. 1 (VOLUME, ENTHALPY, ENTROPY FOR PRESSURE LISTED)

	6000		00000	2061-0	96120	1.7550	1.96.1	1.9588	2.0381	2.1089	2.1733	2.2327		1000			0.1633	1617.0	F000 -	2764-1	110.1	1.076	1.7733	1.8396	1006.1			0.0008	0.0364	0.1290	C.2137	0.4342	0.6836	1.3786	1.5128	1.6018	1.6753	1.7396		0		6760-0	21710	9707-0	2614.0	0.6475	C.8485	1.0413	1.2210	1.3578	1.4576	
	•	\$ ° 0	18.40	68.44	_	1190.49	1286.50	1383.41	1483.21	1586.40	693.1	1803.66		. 82	70 0 7	10.01		114.21	270.87	1231.79	1356.89	1466.74	1575.27	1685.25	1797.72		ļ	6.28	24.14	73.63	123.17	273.67	487.69	1240.21	1407.85	1537.46	1659.15	1778.68		,	*****	17.85	70.01	153.47	298.42	497.40	710.17	953.03	1215.00	1441.21	1626.41	
(cress	25.PSIA	0.01602	0.01602	0.01613	0.01634	17.83861	22.14725	27.56616	32,35859	37.13954	41.91460	46.68645		500.PSIA	66510.0	00010-0	11910.0	0.01632	0.01742	0.99297	1.30445	1.57274	1.82748	2.07580	2.32067		2000.PSIA	0.01591	0.01592	0.01603	0.01625	0.01731	0.02015	0.24895	0.35357	0.43259	0.50325	.5697		14500.PSIA	0.01532	0.01536	16510.0	0.01571	0.01659	0.01848	0.02177	0.02863	0.04189	0.05745	0.07136	
		9000	0.0367	0.1302	0.2156	1.9369	2.0460	2,1369	2,2159	2.2865	2.3508	2.4102			0000	0.0367	0.1301	0.2154	0.4374	1.6241	1.7236	1.8056	1.8777	1.9428	2,0026	!		0.0007	0.0365	0.1293	0.2142	0.4351	0.6857	1.4432	1-5564	1.6400	1.7109	. 773			-0.0003	0.0341	0.1239	0.2066	0.4215	0.6582	0.8711	1,1023	1.3066	1.4309	1.5201	
ENITOFI FOR FREESOME LIBITAL		0.33	18.41	68.39	118.29	1194.96	1288.35	1384.46	1483.88	1586.86	1693.51	803.9			0.92	18.97	68.90	118.77	210.32	1268.98	1374.03	1477.26	1582.35	1690.28	1801.48			4.80	22.71	72.32	121.95	27.27.2	487.78	1286.91	1428.71	1550.48	1668.01	1785.06			20.62	46.26	94.26	142.63	289.30	492.17	717.72	1009-66	1306.31	1511.71	1677.32	
ENTHALFY,	S.PSIA	0.01602	0.01602	0.01613	0-01634	90.27881	114.24379	74501.951	161-97760	195 92012) C	33.4902		200.PSIA	0.01601	0.01601	0.01612	0.01633	0.01744	2.72497	3,38019	4.00394	4.61550	5.22098	F 82316	1070*	1500.PSIA	40310.0	*64.C	70710	0.01637	170100	50000	79176	00000	•	70000	0 76422	•	10000.PSIA	0.01552	0.01555	0.01569	0.01589	0.01682	40810-0	0.000	736300	0.06339	0.08652	0.10536	1 1 1
(NOTOME,		0.0006	0.0367	0.1302	2 0154	2,1152	7,11,1	17707	7505 6	1777	7.4040	2.5877			0.0007	0.0367	0.1302	0.2155	0.4376	1.7087	1 8034	1.8839	1 0667	2.0109	1010	20.		1000	2000	0000	0.170	0.57.0	0.4360	8,80.0	1.515.	7719-1	£0.60* 1	1.00	7170-1		900000	035	0.1271	0.110	2017	2424	0.000	1016.	1.3194	1 6404	1-5494) i i) i i
		0.33	96.	40.04	07 66.	1001711	CO*C411	77.0071	1364.00	70.101	1250.42	1803.96			0.62	18.68	49.89	118.53	270.14	1270.20	77 0461	1400 47	0.0041	1004001	1011	1802.73			16.6	87.17	71.01	120.13	271.80	487.94	1324.80	16.84.41	1563.09	71.0101	141.41		15.02	32.59	81.44	07 021	1000	74.617	488.31	141.13	1251.62	04.7641	1503.91	
,	E, 1.PCIA	20710	0.01602	0.0100	61910-0	362.16902	10004-764	1977/11/6	690.91043	810.018	ъ,	1048.36766	:	100.PSIA	0.01602	0.01602	20100	46410	746	0 10 0	0000000	0.03000	204000	. 261	6704.	11.66076	-	1000.PSIA	0.01597	0.01597	0.01608	0.01629	0.01738	0.02036	0.60831	0.76125	0.89784	1.02740	1.15327	4100 0004	01576	2.4.0		26.70	0.01611	0.01711	0.01961	0.02679	0.10396	0.15309	0.18924	777
	TEMPERATURE,	- e	32.	• • • • •	100.	150.	300	200.	100	900	1100.	1360.	•		13				100	200	•000	.00.	006	1100.	1300.	1500.			32.	50.	100.	150.	300.	500.	100.	.006	1100.	1300.	1500.			. 76	•	001	150.	300	200	700.	-006	1100.	1300.	1500-

COMPARISON POINTS FOR ASME TABLE 4, REF. 1

LISTED
PRESSURE
FOR
ENTROPY
ENTHALPY,
(VOLUME,

		0.8691	0.9214	1.2209	1.2901	1.111	1.3626				0.8672	0.9174	1.1748		1.2.100	1.3164	1.3502				00000	\$016°3	0.9835	1.2186	1.2826	1.3230			A B B B		*****************	1926.5	1.0870	1.2218	1 2784	70-4-1
		084.39	743.32	1040.07	1171.94	1221.96	1260.89				682.96	739.51	1037.53	1161 22	77-1611	1207.56	1249.55			6 6 6 7	2000	(33.03	817.62	1095.59	1173.17	1223.51			676.62	725.68	20000	188.97	943.88	1106.84	1177.05	\\
TED)	3060. PSIA	0.02540	0.02863	10001.0	0.13587	0.15508	0.17055		2200 BC 1 A	4 C 1 C 1 C 1 C 1 C 1 C 1 C 1 C 1 C 1 C	0.02524	0.02819	0.08560	0.1224B	00771.0	105+1-0	0.15881		3500, PC1A	20100	0.0243	0.02/45	0.03427	0.09532	0.11958	0.13643		3960.PSIA	0.02452	0.0262	75070.0	202000	0.05088	0.08799	0.10766))) 0)
SSURE LIST	0078	6666	0.9653	100717	1. 2982	1.3375	1.3678			1	0.8677	0.9165	1.1901	1.2759	1000	10 2C -1	1.3537			0.9444		07160	0.9983	1.2375	1.2942	1.3322			0.8600	0.9046	0.0423		1.1416	1.2444	1.2946) • •
OPY FOR PRE	40.884		1104 10	61-0011	1180.12	1227.86	1265.61	E LISTED			083.30	740.53	1055.90	1157.40	1211 77	1 - 7	1252.84	E LISTED		481.07	726 00	200	834.31	1116.37	1185.24	1232.48	E LISTED		677.19	727.98	705.78	>	1007.64	1132.29	1194.68	,
(VOLUME, ENTHALPY, ENTROPY FOR PRESSURE LISTED)	3000.PSIA	- rock o	0-11425	771110	0-141-0	0.16052	0.17588	PY) FOR PRESSURE	3160.PSIA		0.0258	T6R20*0	0.09228	0.12640	0.14638	000110	0.16207	PY) FOR PRESSURE	3400.PSIA	0.02503	0-02767	10170	0.03675	0.10443	0.12707	0.14351	(VOLUME,ENTHALPY,ENTROPY) FOR PRESSURE LISTED	3800.PSIA	0.02465	0.02688	0-03134		0.06610	0.09854	0.11704	1
(VOLUME,	0.8719	0.0285	1-2648		7916-1	1.3518	1.3801	(VOLUME, ENTHALPY, ENTROPY)		***	00000	7076-0	1.2097	1.2845	1.3271		1.3590	(VOLUME, ENTHALPY, ENTROPY)		0.8664	0.9159		7961-1	1.2608	1.3099	1.3448	THALPY, ENTROS		0.8623	0.9084	0.9748		1761-1	1.2704	1.3137	
	686.64	750.28	1137.05	1107 03	7601611	10.1421	1276.31	(VOLUME, EN		402 07		01 • 74	1077.79	1166.26	1217.94	1061	1627.00	(VOLUME,EN		682.37	738.06	74 700	770.14	1141.52	1201.10	1244.54	(VOLUME,EN		679.36	731.23	808.03	1071 47	1101	1160.39	1214.24	
	2860.PSIA 0.02565	0.07946	0.13149	1686		****	0.18909		3100.PSIA	A5350.0		64B20*0	0.10109	0.13205	0.15155	017410	01.01.0		3260.PSIA	0.02517	0.02802	0.07262	507.000	01110	0.13808	0.15405	-	3600.PSIA	0.02483	0.02724	0.03294	0.00	100000	0.11235	0.12967	
TEMPERATURE.	oF 650.	680.	710.	740	9.6	•	800.			650.			.01/	740.	770.	C	•			650.	680.	710.			770.	900		•	650.	.089	710.	740.		•	800.	

	10000	ı	0.958	•	986.0	1.246	1.202		0.11	
	6000		64	•	1.002	1.526	106.0	· · · · · · · · · · · · · · · · · · ·	0.682	
	3000		6	0000	1.015	998.9	481		0.617	
		•0001	•	66.0	1.025	0.678		0.0	0.578	
(F.F. 1	•	• 00 •		1.001	1.028	0.547		146-0	0.568	
TABLE 9, F ./(lbm)(°R)		200.		1.002	1.029	515		0.532	0.565	
COMPARISON POINTS FOR ASME TABLE 9, MEF. 1 (specific HEAT, C . Btu/(lbm)(OR))	, a	100.		1.003	1.029		100.0	0.528	0.563	
SON POINTS FOIRIC HEA		•09		1.003	0.536		0,40	0.526	0.562	
COMPARI	5	30.		1.003	404		264.0	0.525	679	
		10.		1.003	077	•	0.489	0.524		796.0
		<i>;</i>		1,003		104.0	0.488	0.524	,	0.561
		:		,	50.1	0.458	0.488	0.524		0.561
		PSIA	TEMP	;	• 75	300.	100.	. 100		1500.

COMPARISON POINTS FOR TABLE 6a, REF. 2

((VISCOSITY,	(VISCOSITY, $10^{-6} \text{ kg/(m)(sec)}$)			
٦, °C	1.BARS	50.BARS	200.BARS	350.BARS	500. BAR	4	į
10.	1299.29	1297.83	1293.37	1288.00		000 • 0 × 0 × 0	800 BAR
50.	544.10	17 775		06.8031	1284.44	1279.98	1275.52
5		10.11	11.040	547.72	549.27	550.82	552.38
•	17.71	279.93	282.92	285.91	288.90	291.85	294.88
120.	12.92	230.94	234-12	237.31	240.50	243, 48	
140.	13.74	195.97	199.28	202.60	205.91		10.017
160.	14.55	170.04	173.45	176.86	1000	53.403	212.54
180.	15,37	150.22	153.69	16.2 13	0 0	183.67	187.08
200.	16.18	134.63	138 17		100.65	164.13	167.60
220.	16.99	122 00	1100	141-11	145.25	148.75	152.32
97.		60.531	125.69	129.28	132.87	136.47	140.06
.042	17.81	111.78	115.42	119.07	122.71	126. 16	0
260.	18.62	103.12	106.81	110.51	134.21		130.00
280.	19.44	18.95	\$ 7 66			36 - 11	121.60
300.	20.25			61.501	106.94	110.65	114.44
	67107	90*17	90.52	97.01	103.09	108.95	114.70
360	21.06	21.83	81.70	88.38	94.39	100.05	105.41
340.	21.88	22.60	73.28	80.63	86.68	42,24	
360.	22.69	23.38	63.46	73.53	70.84) (000
.004	24.32	24.04	900		00.6	80°38	90.57
500.	00		46.87	57.33	68.92	75.04	79.57
	66.93	28.92	31.08	34.89	42.01	51.43	59,39
• 000	32.46	32.92	34.60	36.90	40.05	44.15	
700.	36.53	36.94	38.34	40.04	6 6 7	•	****
				`	27.74	44.17	47.70

10.46 110.33 110.12 110.12 110.04 110.07 110.24 110.25 110.87 110 12000 9.90 9.90 9.90 9.52 9.52 9.52 9.51 10.61 11.69 1 10000 1500. 5000 2000. 1000 COMPARISON POINTS FOR ASME TABLE 10, REF. 1 slugs/(ft)(sec)) 8.65 8.43 8.43 17.73 17. 500 8.63 8.60 8.60 17.69 200 8.55 9.55 (VISCOSITY, 10-5 8 86.98 86.38 86.38 7.64 7.64 7.64 7.64 7.64 6.95 8.08 8.0 80. 86.62 81.49 17.61 17 20. 88.89 88.99 88.99 88.99 17.61 17.61 17.61 17.61 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 18.91 9 86.98 86.38 87.41 77.43 11.43 86.38 86.42 86.42 86.43 86.43 87.43 88.93 88.93 88.81 88.81 88.81 88.83 88 88.90 17.61 17.61 17.61 17.61 17.61 17.61 17.61 17.61 17.61 17.61 18 88.36 88.36 88.36 88.36 88.36 88.36 7.46 7.46 86.36 86

COMPARISON POINTS FOR TABLE 6a, REF. 2 (THERMAL CONDUCTIVITY, 10-2 W/(m)(K))

					FHERMAL C	(THERMAL CONDUCTIVITY, 10-	ry, 10-5 v	W/(m)(K))					
P-BARS	1.	10.	25.	50.	100	150.	200.	250.	300.	350.	*00*	450.	500.
1,°C													
10.	58.70	58.78	58.91	59.12	59.53	59.94	60.33	60.70	61.07	61.41	61.75	62.07	62.38
50.	64.33	14.49	64.53	64.74	65.14	65.52	65.89	66.24	66.58	06.99	67.20	67.49	67.76
100.	2.45	68.14	68.24	68.42	68.77	69.11	69.45	69.77	70.09	70.40	10.69	10.98	71.27
120.	19.2	68.72	68.82	66.89	69.33	99.69	86.69	70.31	70.62	10.93	71.24	71.54	71.84
140.	2.17	68.82	68.92	60.69	69.42	69.75	10.08	10.41	70.73	71.06	71.38	71.70	12.01
160.	2.95	68.46	68.57	68.74	60.69	69.43	69.77	70.12	70.46	70.80	71.14	71.48	71.82
180.	3.13	3.41	67.77	67.96	68.34	68.72	60.69	69.47	69.83	70.20	10.56	70.93	71.28
200.	3.31	3.51	66.54	66.76	67.20	67.63	90-89	68.47	68.89	69.28	69.68	70.07	10.44
220.	3.51	3.66	64.86	65.13	99.59	66.17	19.99	67.16	67.62	68.07	68.50	68.92	69.32
240.	3.71	3.84	4.25	63.02	63.69	64.33	64.93	65.51	66.05	66.57	67.05	67.50	67.92
260.	3.91	4.03	4.34	60.39	61.25	62.05	62.81	63.51	64.16	64.76	65.31	18.39	92.99
280.	4.12	4.23	4.48	5.27	58.24	59.27	60.23	61.11	61.92	62.64	63.29	99.69	64.35
300.	4.34	****	4.65	5.25	54.51	55.87	57.10	58.23	59.24	60.14	60.93	19.19	62.17
320.	4.56	4.65	4.84	5.32	7.52	51.62	53.24	54.71	10.95	57.17	58.16	99.00	59.69
340.	4.78	4.87	5.05	5.46	7.00	46.21	48.35	50.29	52.01	53.52	54.83	55.93	56.82
360.	5.01	5.10	5.27	5.62	6.81	9.50	41.22	****	46.79	48.82	50-63	52.26	53.70
00	5.48	5.57	5.72	6.02	6.86	8.22	10.73	15.49	26.38	35.11	38.85	41.51	43.77
500.	6.13	6.82	96.9	7.20	7.76	8.43	9.26	10.29	11.58	13.22	15.32	17.96	20.22
•009	8.05	8.14	8.27	8.50	8.98	9.51	10.09	10.73	11.42	12.19	13.02	13.94	14.94
700.	9.42	9.50	9.63	9.85	10.31	10.79	11.29	11.81	12.36	12.93	13.52	14.14	14.79

COMPARISON POINTS FOR ASME TABLE 11, REF. 1

PSIA	;	5	5.	10.	50. 100.	50.	100.	200.	\$00.	1000.	2000.	5000.	1500.
т. Э						:	;	;		11 11	70 73	80.08	47.27
1500.	63.72	63.72	63.72	63.72	63.19	63.89	90.40	04.	60.67	46	A. S.	80.12	90.67
1450.	61.50	61.50	61.50	61.50	01.20	01.0	10.10	07.70	1000	42.54	66.37	78.22	89.21
1400	59.27	59.27	59.27	59.27	59.34	94.44	10.46	74.47	00.13		44.21	76.39	87.95
1350.	57.04	57.04	57.04	57.04	57.11	57.21	37.38	V	7000	00°00	42.64	74.66	86.95
1300	54.82	54.82	54.82	24.82	24.89	7.00	22.10	10.00	70.00	71	80.04	70.67	86.33
1250.	52.61	52.61	52.61	52.61	52.68	52.78	52.95	53.50	74.04	70.14	K7 . K3	71.68	86.26
1200.	50.41	50.41	50.41	50.41	50.48	20.00	20.13	51°03	49.97	51. B1	55, 77	70.56	87.01
1150.	48.22	48.22	77.84	77-84	47.04	40.37	00.04	7, 77	47.91	40.68	53.77	69.85	89.08
1100.	46.05	46.05	46.05	46.00	40-12	77.04	10.37	44	45.67	47.58	51.84	69.17	93.39
1050.	43.90	43.90	43.90	06.64	10.4	00.14	42 12	17-64	43.56	45.51	50.01	70.72	103.03
1000	41.78	41.78	41.78	91.00	10.14	20 05	FO.04	40.38	41.49	43.50	48.32	73.53	115.72
956	39.68	34.68	34.00	27.00	37.40	27.76	37.96	38.32	39.45	41.55	46.83	80.13	138.89
006	10-15	10.10	10.0	40.00	20.00	35.76	35.93	36.29	37.45	39.69	45.65	96.65	178.93
820.	50.00	27.70		94.56	33.66	33.76	33.94	34.31	35.51	37.93	44.99	129.61	216.27
	33.33	44 15	47.15	31.64	31.71	31.81	31.99	32,37	33.64	36.34	45.26	202.45	258.72
• • • • • • • • • • • • • • • • • • • •	FD - 00	20.73	29.73	29.73	29.80	29.91	30.09	30.48	31.85	35.01	47.53	262.30	300.07
	37 87	77.87	27.87	27.87	27.94	28.05	28.24	28.64	30.18	34.12	55.63	304.32	326.85
• 000	24.07	70.04	26.07	26.07	26.14	26.24	26.44	26.88	28.69	34.10	301.91	333.84	240.45
	26.45	26.45	26.31	24.31	24.38	24.50	24.70	25.20	27.50	36.09	333.79	356.27	368 - 12
	22 62	22.62	22.62	22.62	22.69	22.81	23.04	23.64	26.90	350.92	357.54	374.00	383.83
• • •	20.22	20.98	20-98	20.98	21.06	21.19	21.47	22.27	368.22	370.70	375.45	388.08	396. 72
004	19.42	19.42	19.42	19.42	19.49	19.65	20.03	21.28	383.22	385.06	388.66	396.86	900
	17.91	17.91	17.91	17.91	18.00	18.22	18.82	392.26	393.15	394.64	397.60	406.33	06.616
000	14.49	16.49	16.49	16.49	16.60	16.91	397.16	397.43	398.24	399.59	402.27	410.21	416.73
		5.1.2	15.13	15.13	15.33	397.16	397.30	397.57	398.39	399.73	402.39	410.05	416.08
.000		20.00	13,85	13.85	391.87	391.96	392.11	392.40	393.28	394.72	397.51	405.25	410.95
	****	12.66	380.87	380.89	380.92	381.02	381,18	381.50	382.46	384.02	387.02	395.08	400 - 69
.001	00.21	77 676	26.26	363-67	363.70	363.80	363.98	364.32	365.34	367.00	370.19	378.67	384.48
	200000	100000	230.57	339.54	139.58	339.68	339.86	340.20	341.23	342.91	346.17	355.06	361.44
	334.01	300.000	10.000	200.03	329.06	329.16	329,33	329.67	330.69	332,35	335.59	344.59	351.28
• 7 6	363.00	****	17.16	******	1	1							

COMPARISON POINTS FOR TABLE 7, REF. 2 (SURFACE TENSION AND LAPLACE CONSTANT)

£ 2:	50	28.5	77.7	25.4	1.484 1.294 1.060 0.734
540	, ~ 8	- 50	7 B N	500	14.39 9.89 5.71 2.03
	10 N	400	0 O O	400	300. 320. 340.

APPENDIX G

METASTABLE SUBROUTINE (PMETAS)

Although property measurements for other than stable states are very difficult to make, metastable states are of interest in heat-transfer and fluid-flow calculations. The fundamental equation

$$\psi = \psi_0(\mathbf{T}) + \mathrm{RT}[\ln \rho + \rho \mathbf{Q}(\rho, \tau)]$$

represents a continuum of single-phase states between the saturated liquid and saturated vapor states which can be classified as either metastable or unstable (as for the Van der Waals equation). Consequently, properties of the superheated liquid and supersaturated vapor can be determined. It is pointed out in reference 3 that between 300° C and the critical temperature, the nonstable states as determined by the fundamental equation have a single maximum and minimum. At lower temperatures, more than one pair of extremum exists for which the authors of reference 3 attach no significance.

The subroutine PMETAS (KU, T, D, P, KR) is provided to illustrate to the user of WASP how the metastable and unstable states can be determined. Given a density D and a temperature T (KU and KR have their usual meanings) the pressure P is returned

$$\mathbf{P} = \rho \mathbf{R} \mathbf{T} \left[1 + \rho \mathbf{Q}(\rho, \tau) + \rho^2 \frac{\partial \mathbf{Q}(\rho, \tau)}{\partial \rho} \right]$$

The user can then formulate a locus of maximum and minimum points, as for the Van der Waals equation, and determine if the point is stable, metastable, or unstable. (Note that PMETAS will also return stable points provided D and T represent a stable point.) Examples of the metastable and unstable loci are given as figures 14.

```
$18FTC PMETA
      SUBROUTINE PMETAS(KU,T,C,P,KR)
C
             -----4/10-72 ------
C
C
C
      THIS ROUTINE CALCULATES PRESSURE FOR ANY T INPUT AND D INPUT.
C
                  THIS ROUTINE DOES NOT DEFINE A REGION AND IS NOT
С
                  CALLED BY -WASP-. THE USER CALLS IT DIRECTLY AND
C
                  IT CAN BE USED IN THE METASTABLE STATE.
C
C
      COMMON /CONV3/PCCNV(5)
      COMMEN /TPARAM/TS
      COMMON /CONSTS/ TAUC, RHOA, RHOB, TAUA, E, R
      COMMEN /CHECKS/ CCH1, CCH2, PCH1, PCH2, PCH3, TCH1, TCH2, TCH3, DST, TST,
     1HSCH1, HSCH2
      COMMON /IERROR/IROUT
      DS= DCHECK(KU,D)
      TS= TCHECK(KU, KR, T)
C
      IROUT= 2
C
C
                  ONE EQUATION FOR ALL REGIONS
C
      CALL QMUST(DS)
      CALL QMUST2(TS)
     PS= 1C00.*R*DS/TS*(1.+DS*(QCALC(TS)+DS*QDT(DS,TS)))
   90 P= PS*PCONV(KU)
      RETURN
      END
```

APPENDIX H

THERMODYNAMIC RELATIONS AND DERIVATIVES

The symbols C_p , C_v , H, P, R, S, T, and ρ have the same meaning as defined elsewhere in this report. The other symbols used exclusively in this appendix are defined as follows:

A = E - TS Helmholtz free energy or work content

E internal energy

F = H - TS Gibbs free energy or free energy

K equilibrium constant

V specific volume

To illustrate the facility of the partial derivatives, Roder and Weber (ref. 17) give five which are useful to engineers:

Specific heat input:

$$\mathbf{V} \left(\frac{\partial \mathbf{H}}{\partial \mathbf{V}} \right)_{\mathbf{P}} = \rho \mathbf{C}_{\mathbf{p}} \left[\frac{\left(\frac{\partial \mathbf{P}}{\partial \rho} \right)_{\mathbf{T}}}{\left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}} \right)_{\rho}} \right]$$

Energy derivative:

$$\mathbf{V} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{E}} \right)_{\mathbf{V}} = \frac{1}{\rho \mathbf{C}_{\mathbf{V}}} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}} \right)_{\rho}$$

Isothermal bulk modulus:

$$\mathbf{V} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{V}} \right)_{\mathbf{T}} = - \rho \left(\frac{\partial \mathbf{P}}{\partial \rho} \right)_{\mathbf{T}}$$

Volume expansivity:

$$\frac{1}{V} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} = \frac{1}{\rho} \frac{\left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}} \right)_{\rho}}{\left(\frac{\partial \mathbf{P}}{\partial \rho} \right)_{\mathbf{T}}}$$

The background material necessary to derive these and other parameters as the Joule-Thomson coefficient

$$\mu = \frac{1}{\rho C_{p}} \left[\frac{T}{\rho} \frac{\left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\rho}}{\left(\frac{\partial \mathbf{P}}{\partial \rho}\right)_{\mathbf{T}}} - 1 \right]$$

can be found in most thermodynamic texts.

WASP provides the partial derivatives $(\partial P/\partial \rho)_T$ and $(\partial P/\partial T)_\rho$. With the aid of the following thermodynamic derivatives and the Bridgeman Tables, any thermodynamic parameter can be found. The following thermodynamic tables were taken from reference 18.

Differential energy formulas:

$$dE = T dS - P dV$$

$$dH = T dS + V dP$$

$$dA = -S dT - P dV$$

$$dF = -S dT + V dP$$

Maxwell relations:

$$\left(\frac{\partial \mathbf{T}}{\partial \mathbf{V}}\right)_{\mathbf{S}} = -\left(\frac{\partial \mathbf{P}}{\partial \mathbf{S}}\right)_{\mathbf{V}}$$

$$\left(\frac{\partial \mathbf{T}}{\partial \mathbf{P}}\right)_{\mathbf{S}} = \left(\frac{\partial \mathbf{V}}{\partial \mathbf{S}}\right)_{\mathbf{P}}$$

$$\left(\frac{\partial \mathbf{S}}{\partial \mathbf{V}}\right)_{\mathbf{T}} = \left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\mathbf{V}}$$

$$\left(\frac{\partial \mathbf{S}}{\partial \mathbf{P}}\right)_{\mathbf{T}} = -\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

Energy-function derivatives:

$$\left(\frac{\partial \mathbf{E}}{\partial \mathbf{S}}\right)_{\mathbf{V}} = \left(\frac{\partial \mathbf{H}}{\partial \mathbf{S}}\right)_{\mathbf{P}} = \mathbf{T}$$

$$\left(\frac{\partial \mathbf{E}}{\partial \mathbf{V}}\right)_{\mathbf{S}} = \left(\frac{\partial \mathbf{A}}{\partial \mathbf{V}}\right)_{\mathbf{T}} = -\mathbf{P}$$

$$\left(\frac{\partial \mathbf{H}}{\partial \mathbf{P}}\right)_{S} = \left(\frac{\partial \mathbf{F}}{\partial \mathbf{P}}\right)_{T} = V$$

$$\left(\frac{\partial \mathbf{F}}{\partial \mathbf{T}}\right)_{\mathbf{P}} = \left(\frac{\partial \mathbf{A}}{\partial \mathbf{T}}\right)_{\mathbf{V}} = -\mathbf{S}$$

Heat-capacity relations:

$$C_{\mathbf{V}} = \left(\frac{\partial \mathbf{E}}{\partial \mathbf{T}}\right)_{\mathbf{V}} = \mathbf{T} \left(\frac{\partial \mathbf{S}}{\partial \mathbf{T}}\right)_{\mathbf{V}}$$

$$\mathbf{C}_{\mathbf{P}} = \left(\frac{\partial \mathbf{H}}{\partial \mathbf{T}}\right)_{\mathbf{P}} = \mathbf{T} \left(\frac{\partial \mathbf{S}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$C_{\mathbf{P}} - C_{\mathbf{V}} = - T \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}}^{2} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{V}} \right)_{\mathbf{T}}$$

$$C_{\mathbf{P}} - C_{\mathbf{sat}} = T \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}} \right)_{\mathbf{sat}}$$

$$\left(\frac{\partial \mathbf{C}_{\mathbf{V}}}{\partial \mathbf{V}}\right)_{\mathbf{T}} = \mathbf{T} \left(\frac{\partial^2 \mathbf{P}}{\partial \mathbf{T}^2}\right)_{\mathbf{V}}$$

$$\left(\frac{\partial C_{\mathbf{P}}}{\partial \mathbf{P}}\right)_{\mathbf{T}} = -\mathbf{T}\left(\frac{\partial^2 V}{\partial \mathbf{T}^2}\right)_{\mathbf{P}}$$

Effect of P or V on H or E:

$$\left(\frac{\partial \mathbf{H}}{\partial \mathbf{P}}\right)_{\mathbf{T}} = \mathbf{V} - \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$\left(\frac{\partial \mathbf{E}}{\partial \mathbf{V}}\right)_{\mathbf{T}} = \mathbf{T} \left(\frac{\partial \mathbf{P}}{\partial \mathbf{T}}\right)_{\mathbf{V}} - \mathbf{P}$$

Temperature effect on $\Delta F/T = -R \ln K$:

$$\begin{bmatrix} \frac{\partial \left(\frac{\Delta \mathbf{F}}{\mathbf{T}} \right)}{\partial \mathbf{T}} \end{bmatrix}_{\mathbf{P}} = -\mathbf{R} \frac{\partial \ln \mathbf{K}}{\partial \mathbf{T}} = -\frac{\Delta \mathbf{H}}{\mathbf{T}^2}$$

Partial molal quantities, where Y is any extensive quantity:

$$\overline{y}_1 = \left(\frac{\partial Y}{\partial n_1}\right)_{P, T, n_2, n_3, \dots}$$

$$Y = n_1 \bar{y}_1 + n_2 \bar{y}_2 + \dots$$

$$x_1\left(\frac{\partial \overline{y}_1}{\partial x_1}\right) + x_2\left(\frac{\partial \overline{y}_2}{\partial x_1}\right) + \dots = 0$$

$$\left(\frac{\partial \overline{\mathbf{y}}_{\mathbf{i}}}{\partial \mathbf{n}_{\mathbf{j}}}\right) = \frac{\partial^{2} \mathbf{Y}}{\partial \mathbf{n}_{\mathbf{i}} \partial \mathbf{n}_{\mathbf{j}}} = \left(\frac{\partial \overline{\mathbf{y}}_{\mathbf{j}}}{\partial \mathbf{n}_{\mathbf{i}}}\right)$$

The so-called Bridgeman Tables are summarized as follows:

$$(\partial \mathbf{T})_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{T}} = 1$$

$$(\partial \mathbf{V})_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{V}} = \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$(\partial S)_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{S}} = \frac{C_{\mathbf{P}}}{T}$$

$$(\partial \mathbf{E})_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{E}} = \mathbf{C}_{\mathbf{P}} - \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$(\partial \mathbf{H})_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{H}} = \mathbf{C}_{\mathbf{P}}$$

$$(\partial \mathbf{F})_{\mathbf{P}} = -(\partial \mathbf{P})_{\mathbf{F}} = -\mathbf{S}$$

$$(\partial \mathbf{A})_{\mathbf{p}} = -(\partial \mathbf{P})_{\mathbf{A}} = -\left[\mathbf{S} + \mathbf{P}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{p}}\right]$$

$$(\partial \mathbf{V})_{\mathbf{T}} = -(\partial \mathbf{T})_{\mathbf{V}} = -\left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}}$$

$$(\partial S)_{T} = -(\partial T)_{S} = \left(\frac{\partial V}{\partial T}\right)_{P}$$

$$(\partial \mathbf{E})_{\mathbf{T}} = -(\partial \mathbf{T})_{\mathbf{E}} = \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}} + \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}}$$

$$(\partial H)_{\mathbf{T}} = -(\partial \mathbf{T})_{\mathbf{H}} = -\mathbf{V} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$(\partial \mathbf{F})_{\mathbf{T}} = -(\partial \mathbf{T})_{\mathbf{F}} = -\mathbf{V}$$

$$(\partial \mathbf{A})_{\mathbf{T}} = -(\partial \mathbf{T})_{\mathbf{A}} = \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}}$$

$$\left(\partial \mathbf{S}\right)_{\mathbf{V}} = -\left(\partial \mathbf{V}\right)_{\mathbf{S}} = \frac{1}{\mathbf{T}} \left[\mathbf{C}_{\mathbf{P}} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}} \right)_{\mathbf{T}} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}}^{2} \right]$$

$$(\partial \mathbf{E})_{\mathbf{V}} = -(\partial \mathbf{V})_{\mathbf{E}} = \mathbf{C}_{\mathbf{P}} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}^{2}$$

$$(\partial H)_{\mathbf{V}} = -(\partial \mathbf{V})_{\mathbf{H}} = \mathbf{C}_{\mathbf{P}} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}^{2} - \mathbf{V} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}$$

$$(\partial \mathbf{F})_{\mathbf{V}} = -(\partial \mathbf{V})_{\mathbf{F}} = -\left[\mathbf{V}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}} + \mathbf{S}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}}\right]$$

$$(\partial \mathbf{A})_{\mathbf{V}} = -(\partial \mathbf{V})_{\mathbf{A}} = -\mathbf{S} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}} \right)_{\mathbf{T}}$$

$$(\partial E)_{S} = -(\partial S)_{E} = \frac{P}{T} \left[C_{P} \left(\frac{\partial V}{\partial P} \right)_{T} + T \left(\frac{\partial V}{\partial T} \right)_{P}^{2} \right]$$

$$(\partial H)_{S} = -(\partial S)_{H} = -\frac{VC_{P}}{T}$$

$$(\partial \mathbf{F})_{\mathbf{S}} = -(\partial \mathbf{S})_{\mathbf{F}} = -\frac{1}{\mathbf{T}} \left[\mathbf{VC}_{\mathbf{P}} - \mathbf{ST} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} \right]$$

$$\left(\partial A\right)_{S} = -\left(\partial S\right)_{A} = \frac{1}{T} \left\{ P \left[C_{P} \left(\frac{\partial V}{\partial P} \right)_{T} + T \left(\frac{\partial V}{\partial T} \right)_{P}^{2} \right] + ST \left(\frac{\partial V}{\partial T} \right)_{P} \right\}$$

$$(\partial H)_{\mathbf{E}} = -(\partial \mathbf{E})_{\mathbf{H}} = -\mathbf{V} \left[\mathbf{C}_{\mathbf{P}} - \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} \right] - \mathbf{P} \left[\mathbf{C}_{\mathbf{P}} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}} \right)_{\mathbf{T}} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}}^{2} \right]$$

$$(\partial \mathbf{F})_{\mathbf{E}} = -(\partial \mathbf{E})_{\mathbf{F}} = -\mathbf{V} \left[\mathbf{C}_{\mathbf{P}} - \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} \right] + \mathbf{S} \left[\mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}} + \mathbf{P} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}} \right)_{\mathbf{T}} \right]$$

$$(\partial \mathbf{A})_{\mathbf{E}} = -(\partial \mathbf{E})_{\mathbf{A}} = \mathbf{P} \left[(\mathbf{C}_{\mathbf{P}} + \mathbf{S}) \left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}} \right)_{\mathbf{T}} + \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}}^{2} \right] + \mathbf{S} \mathbf{T} \left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}} \right)_{\mathbf{P}}$$

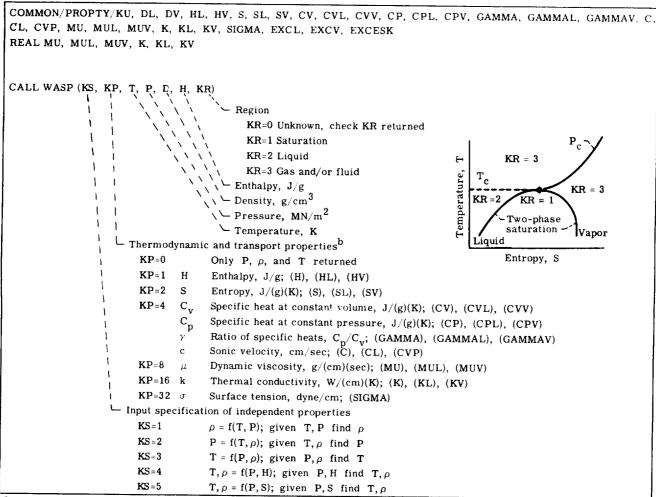
$$\begin{split} \left(\partial \mathbf{F}\right)_{\mathbf{H}} &= -\left(\partial \mathbf{H}\right)_{\mathbf{F}} = -\mathbf{V}(\mathbf{C}_{\mathbf{P}} + \mathbf{S}) + \mathbf{T}\mathbf{S}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}} \\ \left(\partial \mathbf{A}\right)_{\mathbf{H}} &= -\left(\partial \mathbf{H}\right)_{\mathbf{A}} = -\left[\mathbf{S} + \mathbf{P}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}}\right] \begin{bmatrix} \mathbf{V} - \mathbf{T}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}} \end{bmatrix} + \mathbf{P}\mathbf{C}_{\mathbf{P}}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}} \\ \left(\partial \mathbf{A}\right)_{\mathbf{F}} &= -\left(\partial \mathbf{F}\right)_{\mathbf{A}} = -\mathbf{S}\left[\mathbf{V} + \mathbf{P}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{P}}\right)_{\mathbf{T}}\right] - \mathbf{P}\mathbf{V}\left(\frac{\partial \mathbf{V}}{\partial \mathbf{T}}\right)_{\mathbf{P}} \end{split}$$

REFERENCES

- Meyer, C. A.; McClintock, R. B.; Silverstri, G. J.; Spencer, R. C., Jr.: Thermodynamic and Transport Properties of Steam. 1967 ASME Steam Tables. Second ed., ASME, 1967.
- 2. Schmidt, Ernst: Properties of Water and Steam in SI-Units. Springer-Verlag, New York, Inc., 1969.
- 3. Keyes, F. G.; Keenan, J. H.; Hill, P. G.; and Moore, J. G.: A Fundamental Equation for Liquid and Vapor Water. Presented at the Seventh International Conference on the Properties of Steam, Tokyo, Japan, Sept. 1968.
- Benedict, Manson; Webb, George B.; and Rubin, Louis C.: An Empirical Equation for Thermodynamic Properties of Light Hydrocarbons and Their Mixtures.
 I. Methane, Ethane, Propane and n-Butane. J. Chem. Phys., vol. 8, no. 4, Apr. 1940, pp. 334-345.
- 5. Strobridge, Thomas R.: The Thermodynamic Properties of Nitrogen from 64° to 300° K Between 0.1 and 200 Atmospheres. Tech. Note 129, National Bureau of Standards, Jan. 1962.
- 6. Roder, Hans M.; and Goodwin, Robert D.: Provisional Thermodynamic Functions for Para-Hydrogen. Tech. Note 130, National Bureau of Standards, Dec. 1961.
- 7. Bender, E.: Equations of State Exactly Representing the Phase Behavior of Pure Substances. Proceedings of the Fifth Symposium on Thermophysical Properties, ASME, 1970, pp. 227-235.
- 8. Hendricks, R. C.; Baron, A.; Peller, I.; and Pew, K. J.: GASP A Computer Code for Calculating the Thermodynamic and Transport Properties for Eight Fluids Helium, Methane, Neon, Nitrogen, Carbon Monoxide, Oxygen, Argon, Carbon Dioxide. Presented at the XIII International Congress of Refrigeration, NAS/NRC, Washington, D.C., Aug. 27 Sept. 3, 1971.
- 9. Jossi, John A.; Stiel, Leonard I.; and Thodos, George: The Viscosity of Pure Substances in the Dense Gaseous and Liquid Phases. AIChE J., vol. 8, no. 1, Mar. 1962, pp. 59-63.
- 10. Svehla, Roger A.: Estimated Viscosities and Thermal Conductivities of Gases at High Temperatures. NASA TR R-132, 1962.
- 11. Le Neindre, B.; Bury, P.; Tufeu, R.; Johannin, P.; and Vodar, B.: The Thermal Conductivity Coefficients of Carbon Dioxide at High Temperature and High Pressure. Ninth Conference on Thermal Conductivity. Howard R. Shanks, ed. USAEC Rep. CONF-691002, Mar. 1970, pp. 69-93.

- 12. Sengers, J. V.; and Keyes, P. H.: Scaling of the Thermal Conductivity Near the Gas-Liquid Critical Point. Tech. Rep. 71-061, Univ. of Maryland, 1971.
- 13. Hendricks, R. C.; and Baron, A.: Prediction of the Thermal Conductivity Anomaly of Simple Substances in the Critical Region. NASA TM X-52955, 1971.
- 14. Sengers, J. V.: Transport Properties of Gases and Binary Liquids Near the Critical Point. NASA CR-2112, 1972.
- 15. Brokaw, Richard S.: Statistical Mechanical Theories of Transport Properties.

 Presented at the International Conference on the Properties of Steam, Tokyo,
 Japan, Sept. 9-13, 1968.
- Hendricks, R. C.; Simoneau, R. J.; and Smith, R. V.: Survey of Heat Transfer to Near-Critical Fluids. Advances in Cryogenic Engineering. Vol. 15. K. D. Timmerhaus, ed., Plenum Press, 1970, pp. 197-237.
- 17. Roder, Hans M.; and Weber, Lloyd A., eds.: ASRDI Oxygen Technology Survey. Vol. I: Thermophysical Properties. NASA SP-3071, 1972.
- 18. Lewis, Gilbert N.; and Randall, Merle: Thermodynamics. Second ed., McGraw-Hill Book Co., Inc., 1961, pp. 665-668.



^aNotes:

- 1. The units indicator, KU, must be set such that $1 \le \mathrm{KU} \le 5$ or no valid property values can be determined. See table II.
- 2. Reset KR \neq 1 for each call to WASP to be assured of nonsaturation calculations (unless $T = T_{sat}$ and $P = P_{sat}$).
- 3. Sample problem:

```
COMMON/PROPTY/KU, etc. (as above)
REAL MU, etc. (as above)
KU=1
KR=0
T=773.0
D=0.178
```

Call WASP (2, 31, T, P, D, H, KR)

WASP will return P = 40. MN/m^2 , KR = 3, H = 2902. 4, and the following values in COMMON: S = 5. 4689, CV = 2. 4503, CP = 5.7893, GAMMA = 2.363, C = 57415.4, $MU = 0.3682 \times 10^{-3}$, $K = 0.1534 \times 10^{-2}$.

 b KP input is \sum KP options if more than one property is requested. For example, if enthalpy and entropy are desired, set KP equal to 3.

TABLE II. - UNITS SPECIFICATION

Physical quantity		Units specification	
	KU=1	KU=2	KU=3
Temperature	К	К	^o R
Density	g/cm ³	g/cm ³	lbm/ft ³
Pressure	MN/m^2	atmospheres	psia
Enthalpy	joule/g	joule/g	Btu/lbm
Entropy, specific heat	joule/(g)(K)	joule/(g)(K)	Btu/(lbm)(OR)
Sonic velocity	cm/sec	cm/sec	ft/sec
Dynamic viscosity	g/(cm)(sec)	g/(cm)(sec)	lbm/(ft)(sec)
Thermal conductivity	joule/(cm)(sec)(K)	joule/(cm)(sec)(K)	Btu/(ft)(sec)(^O R)
Surface tension	dyne/cm	dyne/cm	lbf/ft

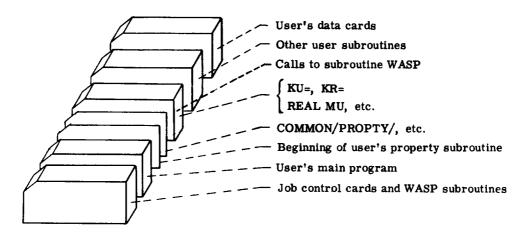
^aKU=4, 5 permit the user to work in other units; however, the proper conversions must be entered into BLOCK DATA. To add special set of units for KU=4 or KU=5:

(1) User's program must contain following COMMON

/CONV1/DCONV(5)
/CONV2/TCONV(5)
/CONV3/PCONV(5)
/CONV4/SCONV(5)
/CONV5/CCONV(5)
/CONV6/HCONV(5)
/CONV7/MCONV(5)
/CONV8/KCONV(5)
/CONV9/STCONV(5)
REAL MCONV, KCONV

(2) Store conversion factors in fourth and/or fifth position of each array such that (D in input unit desired)/DCONV(4) = g/cm³, etc. All conversion factors must change input to units of KU=1. For output then, (D in g/cm³)*DCONV(4) = (D in desired units).

TABLE III. - PROGRAM ASSEMBLY



The subroutines in WASP may be loaded in any order with respect to the user's program. To run successfully, there must appear in at least one user subroutine the following:

- (1) COMMON/PROPTY/, etc.
 - REAL MU, etc.
- (2) KU=1 (or 2, 3, 4, 5)
- (3) Other input variable specifications
- (4) Calls to subroutine WASP

The COMMON/PROPTY/, of course, must be in the main program or subroutine where the user expects answers to be returned from WASP. It could be in several or all user subroutines.

TABLE IV. - COEFFICIENTS OF Q-FUNCTION, ψ_0 -FUNCTION, AND VAPOR PRESSURE CURVE (a) Coefficients of Q-function

i	j						
	1	2	3	4	5	6	7
	Coefficients, A _{ij}						
1	29. 492937	-5. 1985860	6.8335354	-0. 1564104	-6. 3972405	-3.9661401	-0.69048554
2	-132. 13917	7.7779182	-26. 149751	-0. 72546108	26. 409282	15. 453061	2.7407416
3	274.64632	-33. 301902	65. 326396	-9. 2734289	-47.740374	-29. 142470	-5. 1028070
4	-360, 93828	-16. 254622	-26. 181978	4. 3125840	56. 323130	29. 568796	3.9636085
5	342. 18431	-177.31074	0	o.	ó	ó	Q
6	-244. 50042	127. 48742					
7	155. 18535	137. 46153					
8	5. 9728487	155. 97836		₩	♦	♦	₩
9	-410. 30848	337. 31180	-137.46618	6.7874983	136. 87317	79.847970	13.041253
10	-416.05860	-209.88866	-733. 96848	10.401717	645.81880	399. 17570	71. 531353

(b) Coefficients of

 ψ_0 -function

i	Coefficients C _i		
1	1855. 3865		
2	3. 278642		
3	00037903		
4	46. 174		
5	-1.02117		

(c) Coefficients of vapor

pressure curve

i	Coefficients D _i		
1	2. 9304370		
2	-2309. 5789		
3	. 34522497×10 ⁻¹		
4	13621289×10 ⁻³		
5	. 25878044×10 ⁻⁶		
6	24709162×10 ⁻⁹		
7	. 95937646×10 ⁻¹³		

TABLE V. - NECESSARY AND OPTIONAL ROUTINES

(a) Necessary routines

NAME (* indicates multiple entry)	Reason		
BLOCK DATA	Stores coefficients for the fundamental equation		
*(CHECK, TCHECK, PCHECK, DCHECK)	Performs region and limit checks for all subroutines; converts user's units to internal program units		
ROOT ROOTX SOLVE	Mathematical routines used in all iterative solutions necessary to calculation of properties		
QCALC *(QMUST, QMUST2) QTD *(QDTA, QDT) Q2T2D *(Q2DTA, Q2DT) *(Q2D2TA, Q2D2T)	Q-function and derivatives used in equation-of-state calculations (See equations used by all KS and KP options.)		
DENS PSSS *(DSF, DDSF)	Used for KS=1 request and to determine region number for most other KS and KP options		

(b) Optional routines

	· ·	Optional Toutines		
NAME (* indicates multiple entry)	KS or KP option in- volved	Statement numbers in subroutine WASP	Additional conditions for removal	
PRESS	KS=2	20	None	
TEMP TSS *(TSSF, DTSSF) *(TSF, DTSF)	KS=3 (also KS=4 and KS=5)	30 40 45	Must also remove TEMPPH, TEMPPS, TSHF, and TPSF	
TEMPPH *(TSHF, TPSF)	KS=4	40	None	
TEMPPS *(TSHF, TPSF)	KS=5	45	None	
ENTH	KP=1 (also KS=4)	60 40	Must also remove TEMPPH and TSHF	
ENT	KP=2 KS=5	100 45	Must also remove TEMPPS and TPSF	
CPPRL	KP=4	130 to 140	None	
VISC	KP=8	160 to 170	None	
THERM	KP=16	180 to 190	None	
SURF	KP=32	240	None	

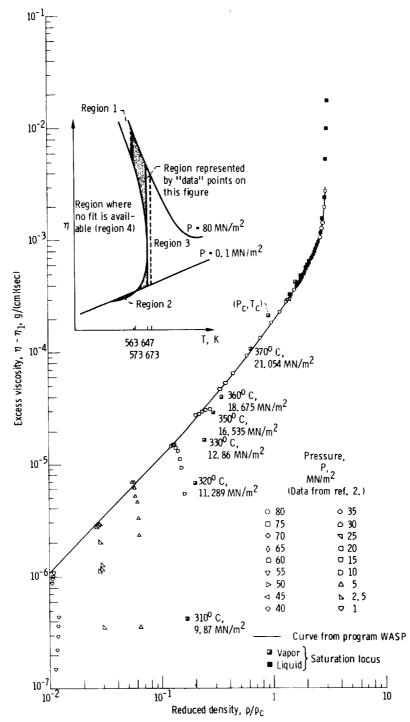


Figure 1. - Excess viscosity as function of reduced density for region 563 K \leq T \leq 673 K.

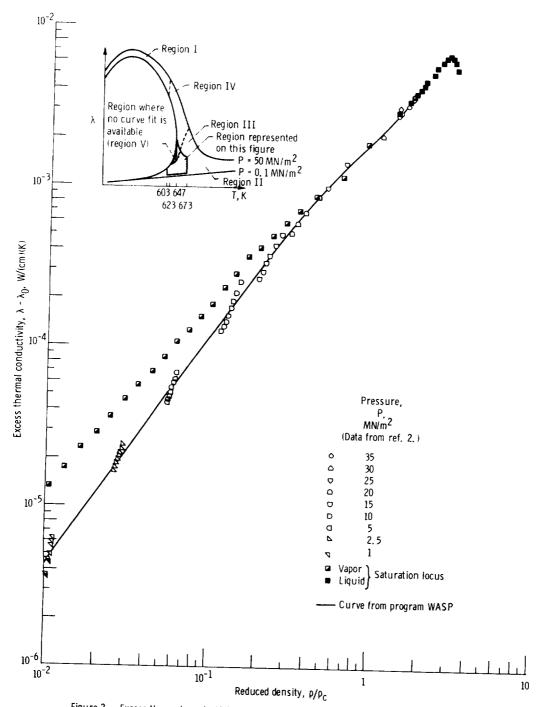


Figure 2. - Excess thermal conductivity as function of reduced density for region 603 K \leq T \leq 673 K.

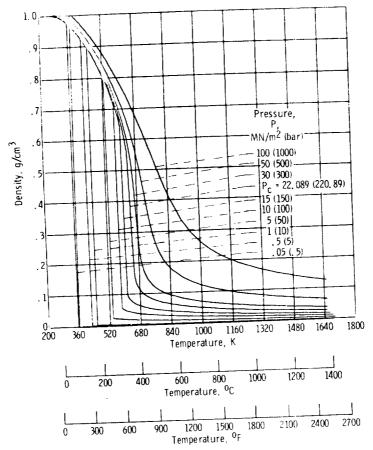


Figure 3. - Density as a function of temperature for selected isobars.

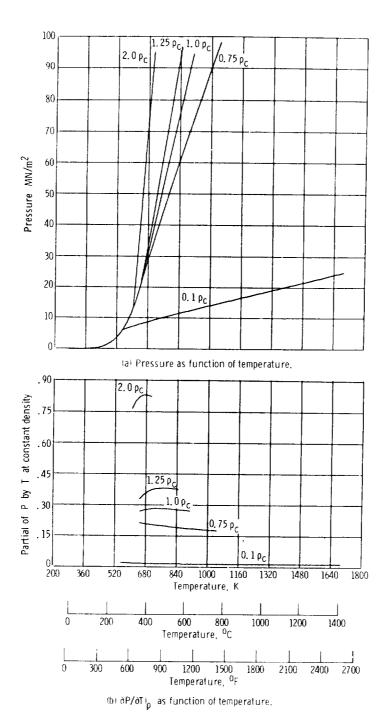
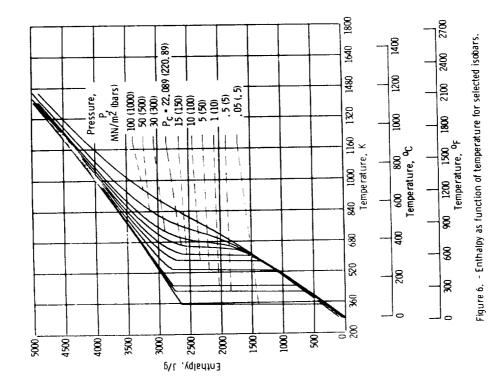
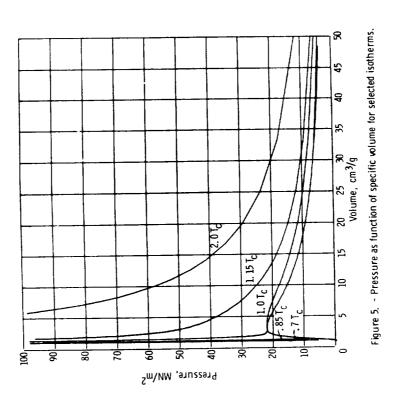
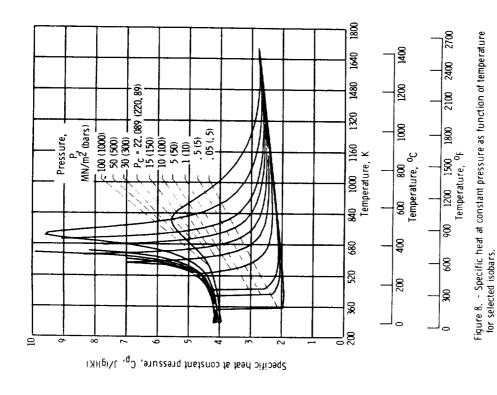
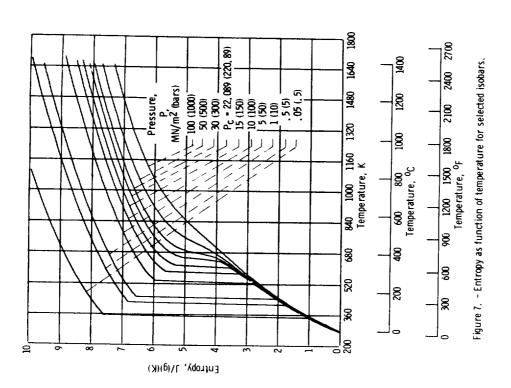


Figure 4. – Pressure and the derivative $|\delta P/\delta T|_p$ as function of temperature for selected isochores.









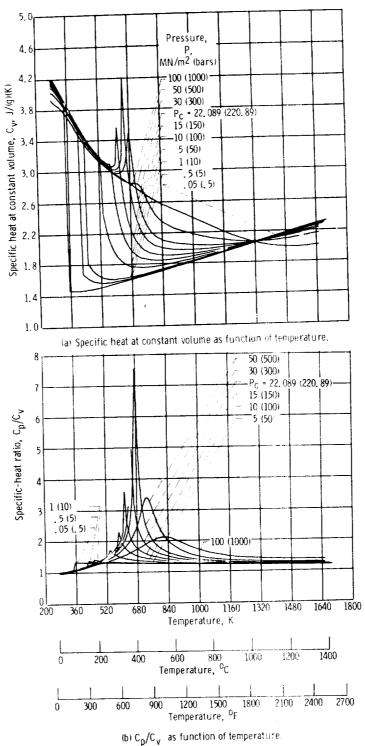
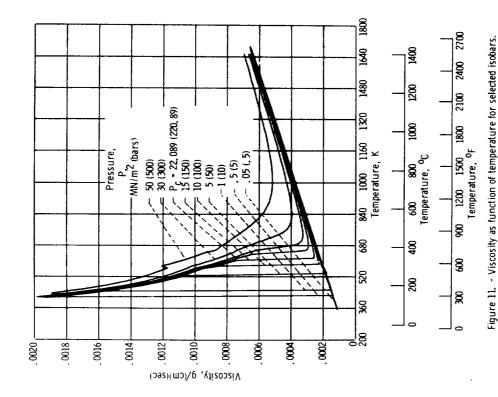


Figure 9. – Specific heat at constant volume and specific-heat ratio $-{\rm C_p/C_v}$ as function of temperature for selected isobars.



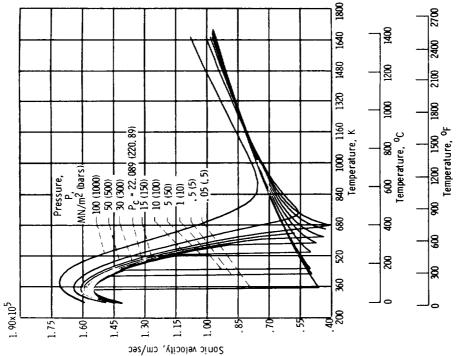
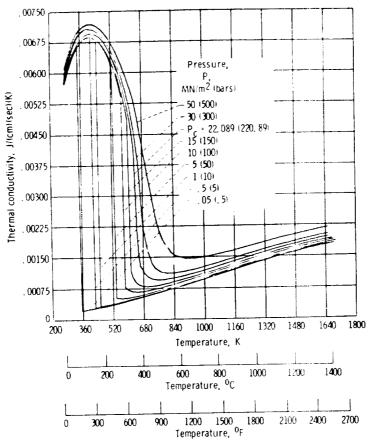
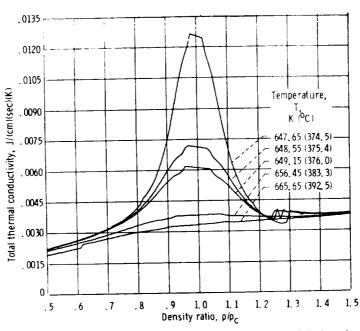


Figure 10. - Sonic velocity as function of temperature for selected isobars.



(a) Thermal conductivity as function of temperature for selected isobars.



(b) Approximation to anomalous behavior of thermal conductivity for water in the near-critical thermodynamic state.

Figure 12. - Thermal conductivity as function of temperature for selected isobars and total thermal conductivity as function of density ratio for selected isotherms.

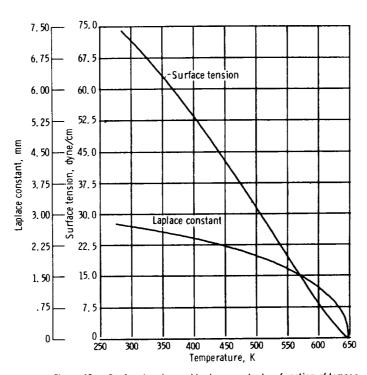


Figure 13. – Surface tension and Laplace constant as function of temperature. $\ \ \,$

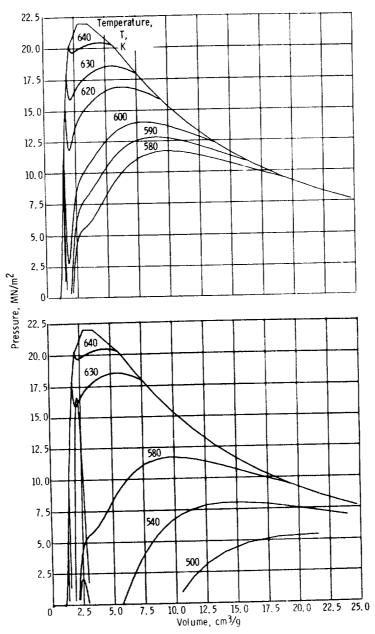
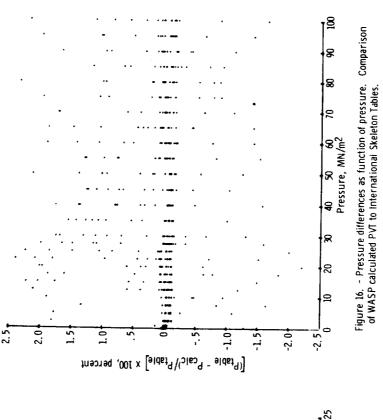


Figure 14. - Pressure-volume relations for metastable region along selected isotherms.



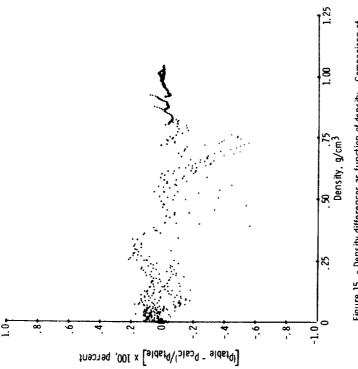


Figure 15. - Density differences as function of density. Comparison of WASP calculated PVT to International Skeleton Tables.

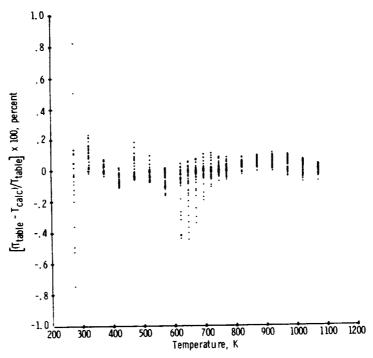


Figure 17. - Temperature differences as function of temperature. Comparison of WASP calculated PVT to International Skeleton Tables.